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ONSET OF CREEP STRESS MEASUREMENTS IN METALLIC MATERIALS

CREEP TEST MACHINE CONSTRUCTION AND OPERATION

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Onset of Creep Stress Measurements in Metallic Materials

Creep Test Machine Construction and Operation

Revised March 1965

National Space And Aeronautics Administration
National Headquarters
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(Reported under Contract NASw-491 by
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FOREWORD

This report was prepared by General Dynamics/Convair under NASA Contract NASw-491. The work was administered by NASA Headquarters with Mr. Richard H. Raring acting as project engineer.

This report covers work performed from November 1962 to March 1965.

1 CREEP TEST MACHINE CONSTRUCTION AND OPERATION

A. Introduction

The onset of creep stress in metallic materials is visualized as a stress intensity at which a threshold of creep activity occurs in various metallic materials as they are heated at various temperatures. The onset of creep stress is considered characteristic of the behavior of a given metallic material at a given temperature.

Plots which portray the creep deformation-time behavior of metallic materials at given temperatures usually show that creep activity diminishes as applied stresses are reduced. These plots also usually show a low but appreciable stress, characteristic of each temperature level, at which creep activity is no longer discernable. From these representations it may be assumed that a lowering of stress at elevated temperatures results in a halting of creep action. Creep theory, however, indicates that this may not be the case. This theory, based upon the Arrhenius equation, holds that creep activity only approaches a zero condition as stresses at elevated temperatures are reduced. Thus it is possible that what may be interpreted from creep-deformation-time plots to be creep halts may in reality represent the limits of discrimination present with the methods used to obtain data. In this situation wherein observed data and methods for interpreting the data disagree, a need for improved data describing the conditions present in the area of disagreement, the creep activity halt region, asserts itself.

Onset of Creep Stress Measurement

As suggested above the investigation of creep activity in threshold regions requires apparatus which extends creep deformation resolutions for measuring small amounts of creep. The apparatus described in detail herein is intended for this purpose. It relies in large degree on close temperature control for the almost complete elimination of thermal expansion transients from creep deformation measurements. It is intended for accurate and reproducible application of loads which remain constant over long periods of time. It is also intended for the measurement of very small creep deformations and uses high resolution strain gaging for this purpose. The construction is massive and extremely conservative in design to preclude machine deformations from creep deformation measurement. The specimens used are one magnitude greater in length than conventional specimens and this device is used to magnify the effects of small incremental length changes.

Onset of Creep Stress Significance in Design

Airframe designs are ordinarily proofed by structural loading tests. In the past room or near room temperature conditions characterized the structural environment, and under these conditions materials properties are relatively constant and time independent. Thus structural tests could be made in expectation of representations that would describe a structure's behavior under loading throughout its useful life. In recent cases, such as the supersonic transport, operating temperatures are so increased that noticeable diminutions in materials properties result. In extreme cases, temperatures can be increased to a degree where materials properties change rapidly in the severe temperature, stress and time environment. In these cases materials properties become time dependent and the behavior of structures made from them can be expected to change as time accumulates. Proofing designs for use in severe thermal environments thus becomes a matter of structural life testing, a drawn out task especially where life times of tens of thousands hours are desired.

In the case of the supersonic transport where the thresholds between time-independent and time-dependent materials properties are crossed, it is important that these thresholds be described. Descriptions which indicate that time-independence of materials is present mean that structural tests of short duration can be made and designs can progress rapidly with confidence. However where time-dependency of materials prevails structural proofing is slowed by the time required for good structural behavior representations. This slows design progress and the acquiring of confidence in design's adequacy. Onset of creep stress data pertains to threshold conditions exhibited by materials, and thus is of importance in establishing design policy since such data can serve descriptions of conditions wherein structures are or are not time dependent in their behavior.

B. Creep Test Frame

General Arrangement

The creep test frame consists of two groups of components: a bed frame assembly, and an array of nine load transmission assemblies. The bed frame assembly includes three sub-assemblies: a bed plate, a stanchion for reacting loads, and a load support column which supports the load application apparatus. The load transmission array consists of nine assemblies, each of which is comprised of a weight hanger, a loading lever and its support, a vertical pull rod assembly, a bell crank with its support, and a specimen grip assembly. The creep test frame outlines are shown in Figures 1 and 2 which indicate the arrangement of major items incorporated into the creep test frame.

Bed Frame Assembly

Bed Plate. The bed plate is the base of the entire creep test machine. It supports the specimen heating unit in addition to serving as a box beam for resisting bending moments caused by specimen loading. The bed plate (Figure 3) is built-up from four 12-inch, 72 pounds per foot, wide flange, structural steel H-beams into a box-beam. The box-beam is assembled by placing the H-beams side by side with their webs vertical and joining the abutting top and bottom flanges with 3-inch long intermittent welds spaced on 12-inch centers. Both box-beam ends are reininforced with 1-inch thick structural steel plates. The load reacting stanchion which reinforces one end of the bed plate is shown to the left in Figure 1. The stanchion backing plate is 1-inch thick structural steel and is extended down to the full depth of the box-beam to stiffen the beam end. The stanchion backing plate is attached to the box-beam by a continuous weld which is run around the periphery of the box beam. The right end of the bed plate (Figure 1) is reinforced by 1-inch thick shaped structural steel plates which are inserted in the rectangular box beam and openings and are secured in place with continuous welds. Lincoln Electric Co. Fleetweld No. 7 welding electrodes were used in bed plate assembly.

In operation the bed plate accepts bending moments from the load reacting stanchion and the load support column. The bed-plate is massive so that its section enables it to resist bending resulting from a 90,000 pound loading with negligible deflection. Stresses in the bed frame assembly are kept to about half the yield strength of the materials used to assure elastic behavior of the materials. The massiveness of the bed plate also permits the test machine to operate as a free standing unit. Thus it does not require special foundations for support.

Stanchion. The load reacting stanchion (Figure 4) which anchors test specimen attachments is a heavily reinforced, open box-beam. It is secured to the bed plate by its end support plate and reinforcing webs which are welded to the base plate and each other. Detail parts incorporated into the stanchion are shown in Figure 5 and Table 1. Continuous fillet welds are used to assemble these parts. Stanchion details are of structural steel. They are joined with Fleetweld No. 7 welding electrodes.

Figure 5 shows the notched locator plate. This plate is not welded into the stanchion. It is left removable to permit ingress of test specimens to the test machine, and is clamped into position by specimen loading forces.

Load Support Column. The load support column (Figure 6) is built up from four sub-assemblies: a horizontal thrust beam, a vertical thrust beam, and a right and a left hand beam support column. The horizontal and vertical thrust beams (Figures 7 and 11) are made massive to resist bending and deflection in any direction.

Horizontal thrust beam construction is detailed in Figures 7, 8 and 9, and Table 1. This thrust beam incorporates 1-inch thick front and rear face plates, a 4 x 7 inch thrust bar, a 1-inch thick top cover plate and 1/4-inch thick stiffening webs, all of structural steel. The thrust bar detailed in Figure 10 is provided with a key-way which is press fitted with a 1/2 x 1/2 inch SAE 1020 cold drawn key. The thrust bar also is provided with sockets at each end to aid in assembly, and to provide for shear transfer into dowels which in turn transmit shear into the support columns. The key aids in locating bell crank supports, and for carrying bell crank thrusts into the thrust bar.

Figures 8 and 9 detail front and rear face plate hole patterns for the insertion of attaching screws. These screws are used to secure bell crank supports and are located at the center line positions shown in Figure 7.

Vertical thrust beam construction is detailed in Figure 11 and Table 1. This beam consists of a 4 x 14 inch block structural steel block which is provided with a 1-inch thick cover plate of sufficient width to receive lever arm supports, and a 1-1/2 x 1-1/2 inch bar to reinforce the block against deflection. The vertical thrust beam reacts downward thrust of six lever arm supports. The horizontal thrust beam reacts downward thrust from only three lever arm supports. The vertical thrust beam is bulky and short to provide access to the pull rod assembly details.

Right and left hand beam support column construction is shown in Figures 12 and 13, and Table 1. These columns support the horizontal and vertical thrust beams above the bed plate. These support columns are double channels which are built-up from 1/2-inch thick structural steel plate. Each column is provided with a shear pad which receives dowel pins for locating the horizontal thrust beam. Shear pad details are shown in Figures 12 and 13 along with foot plate and attaching flange details incorporated into the columns. The foot plates and extension flanges provide for "knock down" assembly of the columns to the bed plate. The foot plates bolt to the bed plate, whereas the extension flanges are screw attached to the bed plate end reinforcements.

The load support column assembly (Figure 6) is, with the exception of the dowel pinning, effected by joining details and sub-assemblies with fillet or grooved butt welds. All details are made from structural steel. Fleetweld No. 7 welding electrodes are used in the continuously welded joints.

Load Transmission Assembly Array.

General Arrangement. The load transmission assembly array consists of nine similar assemblies which vary in detail according to the lengths of components. These variations are introduced to permit accommodation of dead weights within the confines of the creep test machine. The variations are introduced to effect load transmission assemblies in a single vertical plane.

Load transmission assembly variations are in the weight hanger tie rod, lever arm, bell crank, pull rod turnbuckle, specimen grip clevis, and bell crank support components. Six long and three short weight hanger tie rods are used. The short tie rods mate with short lever arms to prevent dead weight settling on the heating unit. Six lever arm assemblies have 20 to 1 ratios: these levers transmit tension into 1 to 1 arm ratio bell cranks. Three lever arm assemblies have 10 to 1 ratios: these levers transmit tension into 2 to 1 arm ratio bell cranks. The different bell crank lengths require length compensations. These are made in the bell crank clevis portion of the specimen grip assemblies. The different bell crank lengths also necessitate bell crank support variations. Turnbuckle and wrench clearance requirements result in pull rod interferences which are compensated by staggering the turnbuckle array in the pull rod system. Table 2 details the specific component arrangements required in the load transmission assemblies and indicates effects resulting from lever arm position reversals indicated in Figure 2.

Weight Hanger Assemblies.* Each weight hanger assembly includes a built-up clevis, a tie rod and a weight support plate as shown in Figure 14 and Table 3. Each clevis is comprised of two side plates and a bottom plate assembled with tongue and groove joints secured with machine screws. The clevises are SAE Type S-1 tool steel hardened to 320,000 psi ultimate strength to enable clevis bearing surfaces to withstand contact with lever arm knife edge pivots. The tie rods are made from 1/2-inch diameter cold drawn SAE 1020 steel. Six tie rods are 40 inches long and

*See also Page 37.

three 37 inches long. Each rod is long enough to accommodate 500 pounds of cast iron standard weights. The weight support plate is a 2 x 4 inch piece of 1/2-inch thick structural steel plate. Tie rods are threaded at each end to permit assembly into threaded clevises and weight support plates. (See page 37)

Weight hanger assemblies are suspended from the lever arms by removing a clevis side bar, slipping paired bars over a lever arm weight hanger pivot and fastening the clevis together again.

Lever Arm Assemblies. Lever arm assemblies are shown in Figure 15. Each assembly consists of a lever arm, weight hanger pivot, fulcrum pivot, and pull rod pivot. Adjusting screws are provided for regulating lever arm lengths and pull rod pivot positioning.

The lever arm detailed in Figures 16 and 17, and Table 3 is provided with three different recesses for receiving knife edge pivots. Weight hanger, fulcrum and pull rod pivot recesses are shown from left to right. A keyhole slot near the weight hanger pivot permits fine adjustment of 15- or 30-inch lever arm lengths by screws provided for opening or closing this slot. The pull rod pivot at the opposite end of the lever arm floats on adjustable set screws. This mounting permits lengthwise and vertical movement of the pull rod pivot for adjusting the length of the 1-1/2-inch arm of all levers. The fulcrum pivots are fixed in recesses machined sqare and in alignment to provide true action of the fulcrum pivot.

The fulcrum pivots are reversible with respect to horizontal positioning. This allows reversal of levers as required in machine assembly. Three lever arm assemblies are used:

1. Three assemblies with 30 and 1-1/2-inch lever arms are according to Figure 15 and are located in the "circled one" positions shown in Figure 2.

2. Three assemblies with 15 and 1-1/2-inch lever arms, but with fulcrum pivots reversed from the Figure 15 position are located in the "circled two" positions shown in Figure 2.

3. Three assemblies with 30 and 1-1/2-inch lever arms, but with fulcrum pivots reversed from the Figure 15 position are located in the "circled three" positions shown in Figure 2.

Levers are made from SAE 4130 steel forged slab, blanked by torch cutting and heat treated to 160,000 psi ultimate tensile strength. The levers are not strength critical. They are heat treated to assure elastic operation under load. These members also are bulky to minimize longitudinal or transverse bending.

Weight hanger, fulcrum, and pull rod pivot detail is shown in Figures 18, 19 and 20 and Table 3. These items are made from SAE Type S-1 tool steel. They are rough machined and hardened to 320,000 psi ultimate strength prior to finishing. Weight hanger and fulcrum pivots are press fitted into their recesses with slight interference.

Pull Rod Assemblies. Each pull rod assembly is made up of an attachment link, a length of roller chain, and a turnbuckle. The attachment link swivels on the pull rod pivot in the lever member and provides a connection for the roller chain. The roller chain, which constitutes the greater part of pull rod length is used to compensate for minor front to rear misalignment of lever members or bell cranks. The turnbuckles provide for pull rod length adjustments required to obtain parallelism between lever and bell crank center lines.

Pull rod attachment link detail is shown in Figure 21 and Table 2. These links are made from SAE Type S-1 tool steel and are hardened to 320,000 psi ultimate strength to enable them to work in conjunction with the lever pivots.

The roller chains are commercial items manufactured by the Link-Belt Company and designated as Rex Type 140 chain.

The turnbuckle assemblies outlined in Figure 22 are comprised of barrels, chain attachment and bell crank attachment clevises. Details of turnbuckle components are given in Figures 23 to 27, inclusive, and Table 3. The pins for attaching the roller chains are not illustrated since they are simple cyclinders with 0.498 to 0.500 inch diameters. Pins 2 15/16 inches long and 1 7/8 inches long respectively attach the chains to the turnbuckle and attachment link clevises. These pins are SAE 4130 steel hardened to 160,000 psi ultimate strength.

Bell Crank Assemblies. Bell crank detail is given in Figure 28 and Table 3. Assembly drawings are not shown since assembly procedure consists only of pressing bearings into three holes in each crank. The bell cranks are made from 7/8 inch structural steel which provides sufficient bulk to satisfactorily stiffen these parts.

Specimen Grip Assemblies.* The specimen grip assemblies consist of two parts: a bell crank attachment and a stanchion attachment sub-assembly. These sub-assemblies are schematically diagramed in Figures 29 and 30.

Bell crank assembly details are shown in Figures 30, 31, 32 and 33. Bell crank connector, coupling stud and lock nut details are given in Figure 31; universal joint details in Figure 33; and specimen grip details in Figure 32.

*See Also Section 2.

The bell crank connector is a combination clevis and threading body for receiving the coupling stud. This stud is adjustable with respect to length and position in the threading body. The lock nut is used to secure the connector and stud after positioning. The connector, stud and lock nut comprise a clevis assembly which attaches to a Boston Gear Company Type J universal joint by means of threads machined into the universal joint.

The specimen grip shown in Figure 32 and Table 3 is recessed at one end to receive a test specimen attachment tab.

The specimen grip and the bell crank clevis included in the sub-assembly are connected by a universal joint which makes the sub-assembly self-alining. To improve alignment between the specimen and the bell crank, the specimen grip clamping surfaces are brought into parallel with the bell crank clevis pin and are locked in position during assembly.

Stanchion attachment details are shown in Figures 29, 32 and 33, and Table 3. This sub-assembly includes the specimen grip shown in Figure 32, a universal joint shown in Figure 33, and the tension rod connector, bearing plate and nut shown in Figure 33. The specimen grip and universal joint features of the stanchion attachment are the same as those of the bell crank attachment (Figure 30). The stanchion attachment employs a tension rod which threads into the universal joint and also passes through the stanchion backing plate for securing with the tension rod nut and its backing plate. The backing plate transmits tension into the stanchion and holds the stanchion locator plate snug. The threads on the tension rod enables it, with its nut, to act as a "take-up" device.

Load Transmission Assembly Supports

Each load transmission assembly is positioned in lever supports mounted on top the load support column, and bell crank supports suspended underneath the hroizontal thrust beam. Each load transmission system is anchored to the creep frame stanchion by a specimen grip attachment tension rod.

Lever Supports* The lever support assemblies are shown in Figure 34. Each consists of a pair of bearing pads and a bearing pad support. Bearing pad support details are given in Figure 35 and bearing pads are detailed in Figure 36. (See page 37)

In initial machining the bearing pad support is roughed slightly oversize with respect to external dimensions. The spacings of the two bearing pad supporting ribs are established and then the two ribs are slotted. At this stage the rough machined bearing pads are fitted into the support ribs by machining their tongues to dimension and inserting them into the slots. Then the support ribs, with the

*See also Page 37.

inserted bearing pads, are drilled to receive 1/8-inch diameter steel dowels. The dowels are lightly peened to secure mating parts. Next the assembly is faced and squared with the base plate preparatory to sizing the bearing pads and machining its curved bearing surfaces. Upon completion of all machining, the bearing pads are removed, hardened to 320,000 psi ultimate strength, and re-installed with heavily peened dowels.

Bell Crank Supports. Two different supports, shown in Figure 37 and Table 3, are used for bell crank suspension. Three large supports suspend the 2 to 1 ratio bell cranks which work with short lever arms. Six smaller supports hold the 1 to 1 ratio bell cranks which operate with long lever arms.

Bell crank support details are SAE 4130 steel assembled by welding with Harnischfeger Corporation P & H 4130 welding electrodes. After welding, assemblies are heat treated to 160,000 psi ultimate strength and finish machined. In initial finish machining the dimensions and squareness of the exterior faces are established for screw hole and key-way slots location. Key-way slots and bell crank pivot holes are then located and machined. Tapped holes for attaching the support end plates and reinforcing bars are located, drilled, and tapped at time of test machine assembly.

Pivots connecting bell cranks to pull rod and specimen grip assemblies, and for bell crank suspension are shown in Figure 38 and Table 3. The bolts in these assemblies are SAE 4130 steel hardened to 160,000 psi ultimate strength after rough machining, and finish ground to dimension. Spacers are cut and ground from SAE 1020 steel bars as required. Assembly fastening is accomplished with castellated nuts which are cotter-keyed after adjustment.

Assembly Procedure

General Arrangement. General arrangement of the assembled creep test frame is indicated in Figures 1 and 2. As mentioned above and summarized in Table 2, three varieties of lever arm and weight hanger assemblies are used as indicated by the circled 1, 2 and 3 numbers in Figure 2. These different arrangements of parts are required to permit dead weight positioning within space limits, and to permit load transmission assembly installation in a single vertical plane. Dead weight interferences require use of two lever lengths and two positionings of the longer levers. Variation in lever length requires two bell crank ratios to obtain a 20 to 1 ratio between dead weight and tension forces for specimen loading. Differences in lever lengths require two weight hanger assembly tie rod lengths for free suspension of dead weights and varied bell rod connectors to compensate for bell crank differences. In addition to interferences set up by dead weight arrangement, close positioning of pull rod assemblies in front of the horizontal thrust beam causes interferences between the turnbuckles in these assemblies. This results in two turnbuckle bell crank clevis lengths to provide working clearance.

Lever Arm Support Positioning. Three lever arm supports are mounted on top of the horizontal thrust beam. Levers carried by these supports extend to the rear. Six lever arm supports are mounted on the vertical thrust beam, three long and three short arms mounted here extend to the front. Front to rear array of these supports and their positioning with respect to the load support column details is shown in Figure 34. Their sidewise positioning in the same regard is shown in Figure 39. Dowel locations which establish alignment of the load transmission assemblies are shown in Figure 40. This figure references dowel positions with respect to reference lines pertaining to loading column positions. Figure 40 also details hole patterns drilled into the loading column top for dowels and clamping bolts. It is essential that the dowel holes match those in the lever arm supports. Dowel engagements provide perpendicularity of lever center lines with load support column reference planes. The 3/8-inch diameter hold-down bolt holes in the load support column are drilled subsequent parts alignment. The assembly is finished by tightening the lever supports bolts.

Bell Crank Support Assembly. Bell crank assembly installation details are shown in Figure 41. Bell crank supports fit into the pocket formed by the load support column front and rear face plates and the thrust bar of the horizontal thrust beam. (See Figure 7). When bell crank supports are inserted into this pocket, their key-way recesses engage the 1/2 x 1/2 inch key installed in the horizontal thrust beam. This key secures the supports from front to rear movement, and permits their sidewise adjustment without disturbance of front to rear positioning. After the bell cranks are located, attaching bolt holes and the front and rear of the supports are located, drilled and tapped. Subsequent to drilling the supports are reinstalled, realigned to assure proper center line spacing, and clamped tight.

To facilitate bell crank installation, bell cranks are installed in their supports prior to the support re-installation after drilling and tapping bolt holes. Bell crank installation requires insertion of bell crank pivots through a support rib, a 1/8-inch thick spacer, the bell crank bearing, a second 1/8-inch spacer, the second support rib and a 5/32-inch spacer, and then threading on a castellated nut which is tightened and keyed with a 1/8-inch diameter by 7/8-inch long cotter key. All pivots are installed from the same side to assure smooth support reinstallation in the thrust beam.

Pull Rod Assembly and Installation. The first pull rod assembly and installation step consists of matching lever arms, pull rod and bell crank assemblies shown in Table 2. Assembly is started by positioning a lever on its support, and by clamping and blocking it in a temporarily fixed position. The pull rod pivot is then removed from the lever arm after backing off the two upper set screws. The chain is installed into the attachment link by alining its pin holes with the attachment link pinholes, and thrusting and positioning the 2 7/8-inch long pin. With the attachment link up, this partial assembly is then passed through the opening between the horizontal and vertical thrust beams. The attachment link is then engaged with the lever arm so that the pull rod pivot can be passed through the attachment link and lever arm openings. After the pivot is positioned, the attachment link is lowered into position on the pivot knife edges. Pivot alignment is restored in the process of fastening it with the set screws provided in the lever arm.

After the chain and attachment link are positioned, the turnbuckle is installed. This is done by engaging the turnbuckle chain clevis with the chain, alining the pin holes and inserting the 1 7/8-inch long pin into its position. The turnbuckle crank clevis is then engaged with the bell crank and a bell crank pivot is installed.

Weight Hanger Assembly Installation. While the lever arm is fixed for pull rod assembly, the weight hanger assembly is installed. The assembly method is described in the weight hanger description.

Load Transmission Assembly Alignment. After the load transmission assembly has proceeded through weight hanger assembly installation, parallelism is established between the lever arm longitudinal center line and the horizontal center line of bell crank pivots by adjusting the pull rod turnbuckle. Following this the assembly is balanced.

Specimen Grip Installation. The specimen grip bell crank attachment assembly (See Figure 30) is attached to the bell crank by means of a bell crank pivot. The installation of this pivot is described under bell crank support assembly procedure.

C. Heater Unit

General Arrangement

The creep test machine heater unit includes three sub-assemblies: a heating "platten," an insulation assembly, and an aluminum alloy enclosure. The heating platten consists of a monel metal core enclosed in a copper heat distributor sheath heated by electrical strip heaters. The insulation assembly is a sheath of asbestos board which envelopes the heating platten and is reinforced with fibrous rock wool batting. The heating platten and its insulation is enclosed in an aluminum alloy box which retains insulating materials and provides reflective insulation.

The monel metal heating platten core is comprised of about five thousand pounds of metal which are a thermal well. The heating platten also is a "thermal flywheel" which damps out thermal fluctuations. This core is a lay-up of 1-inch thick monel metal plates interleaved with asbestos millboard separators. These separators introduce "thermal lag" to damp temperature fluctuations and slow heat losses. Monel metal is used in the core because of its oxidation resistance. Because of minor surface oxidation, the emittance of monel changes little in service. The copper sheathing surrounding the monel metal core receives concentrated heat inputs from electric strip heaters. Because of its high conductivity, the copper sheath distributes heater input throughout its mass for diffused heat transfer into the monel metal core. The use of copper is restricted to sheathing. Copper oxidizes readily in air, and the copper oxide formed on its surfaces radically alters the emittance of the material. Slotted stainless steel bars bind the strip heaters to copper sheathing. This binding permits the heaters to "float" in a longitudinal direction without loss of contact as they contract or expand. The binding also constrains bowing to prevent "hot spot" heating.

Heating Platten Construction

Heating Platten Core. The heating platten core lay-up, from top to bottom, includes the following items indicated in Figure 42 and listed in Table 4:

1. Item 18, 1-inch thick monel metal plate

2. Item 17, 1/16-inch thick asbestos millboard

3. Item 16, 1-inch thick monel metal plate

4. Items 12, 13, 14, 15, a row of 1 1/2-inch deep spacing bars

5. Item 11, 1-inch thick monel metal plate

6. Item 10, 1/16-inch thick asbestos millboard

7. Item 9, 1-inch thick monel metal plate.

Details pertinent to the preparation of the above items for assembly are shown in the following figures:

1. Item 18 and 9, Figure 43

2. Item 17 and 10, Figure 44

3. Item 16 and 11, Figure 45

4. Items 12, 13, 14, 15, Figure 46.

In addition to the top to bottom lay-up, the heating platten core includes the side build-ups, (Figure 42), from left to right, as follows:

1. Item 32, 1-inch thick monel metal plate

2. Item 31, 1/16-inch thick asbestos millboard

3. Item 30, 1-inch thick monel metal plate

4. Top to bottom lay-up

5. Item 23, 1-inch thick monel metal plate

6. Item 24, 1/16-inch thick asbestos millboard

7. Item 25, 1-inch thick monel metal plate

8. Item 23, 25, 30, 32, 1/4-inch thick filler, stainless steel.

The following figures show details pertinent to the preparation of the above items for assembly:

1. Item 30 and 23, Figure 47

2. Items 24 and 31, Figure 48

3. Items 32 and 25, Figure 49

4. Items 23, 25, 30, 32, Figure 50.

Figure 45 shows a set of thirty 3/8-inch diameter through holes in Item 11 and 16 and three 3/8-inch through holes are shown in each item shown in Figure 46. These holes receive dowels which are floating lock pins. These pins maintain the inner plates and spacing bars comprising the central portion of the heater platten core in horizontal alignment. These locking pins are installed with loose fits to permit free expansion or contraction during heating or cooling. The four corner pins holes shown in Figure 43 match holes in Item 9 and 18 details (Figure 43) and receive through lock pins. These pins secure the core plates and separators in the horizontal alignment. The split construction of the 1/16-inch thick asbestos millboards interleaved between the Item 9 and 10, and Item 16 and 18 monel metal plates is shown in Figure 44.

Floating lock pins are not used to assemble side plate Items 30, 31 and 32, and Items 23, 24 and 25 to the left and right sides of the heating platten core. These items are held with stainless steel cap screws.

Heat Distributor. The heat distributor lay-up includes the electrical strip heaters and their clamps, a copper sheath, and an asbestos millboard interlayer which separates the copper sheath from the monel metal core.

The heat distributor lay-up shown in Figure 42 includes, from top to bottom, the following items:

1. Item 22, sixteen heater clamps

2. Item 21, sixteen elctrical strip heaters

3. Item 20, 0.205-inch thick copper heat distributor plate

4. Item 19, 1/8-inch thick asbestos millboard

5. Heating Platten Core assembly

6. Item 8, 1/8-inch thick asbestos millboard

7. Item 7, 0.205-inch thick copper heat distributor plate

8. Item 6, sixteen electrical strip heaters

9. Item 5, sixteen heater clamps.

Heater clamp details (Item 22 and 5) are shown in Figure 51. These clamps are detailed to straddle the strip heaters and press them against the heat distributor plates. Each clamp is fastened with six 1/4-inch cap screws. The copper heat distributor plates (Item 20 and 7) shown in Figure 52 are drilled to a 96-hole pattern which locates the heaters and their clamps. These holes also pass the heater clamp fastening screws through the 1/8-inch thick asbestos millboard which lies next to the copper distributor plates. The 1/8-inch thick asbestos millboard (Items 19 and 8) are shown in Figure 53. This figure indicates the split construction of these items. The hole drilling pattern in this millboard matches the patterns in the heat distributor plates (Items 20 and 7) and the outer heating platten core plates (Item 18 and 9). The heating platten core plates are tapped to receive the 1/4-inch cap screws which secure the heat distributor assemblies in place.

Side heater clamp (Item 36 and 29) details are shown in Figure 51. The copper heat distributor plates (Item 34 and 27) and the 1/8-inch asbestos millboard which assemble to the heater sides are shown in Figures 54 and 55. These items are assembled and fastened with 1/4-inch diameter cap screws which thread into a 32-hole pattern drilled and tapped into each of the heating platten core outer side plates.

End heater clamp (Item 40 and 44) details are shown in Figure 51. The copper heat distributor plates (Item 42 and 38) and the 1/8-inch asbestos millboard (Items 41 and 37) which assemble to the heater ends are shown in Figures 56 and 57. The nine rectangular openings provided in the four items permit ingress of test specimens into the nine channels provided in the heating platten core assembly. The 12-hole drilling pattern in the four items passes 1/4-inch cap screws which secure the heater clamps (Item 40 and 44) and thread into tapped holes provided in the ends of the heat distributor plates (Item 18, 16, 11 and 9).

Heating Unit Insulation

The heating platten core is totally enclosed in a 2-inch thick layer of Johns-Manville Marinite insulation board. This insulation is a dense "asbestos-portland cement" board which combines good compressive load bearing capacity with low thermal conductivity. The inner Marinite enclosure is partially enclosed in a sheath of Johns-Manville Spintex fibrous, rock wool batting. This batting is reinforced as required with Marinite retaining or load bearing pieces. Spintex is used as extensively as possible because of its very low thermal conductivity. The fibrous Spintex is unable to support compressive bearing loads.

The various Marinite items incorporated in the heating core insulation are shown in Figures 58 and 59 and Table 5. These two figures indicate the relative positioning of the several Marinite pieces in the insulation assembly. They do not show the Spintex items. These are installed as required in assembly. Table 5 details the items used for heating platten core insulation.

All of the Marinite items shown in Figures 58 and 59 are accurately machined to the dimensions shown in detailed descriptions. It is essential that this machining be precise to provide assembly that results in a tightly closed enclosure which minimizes heat leaks.

Bottom Insulation. Three 2-inch thick Marinite panels (Item 2, 3 and 4) shown in Figure 60 and 61 insulate the heating platten core bottom and support it on the creep test machine bed plate. The two lower pieces (Item 2 and 3) in addition to supporting the heating platten core, also support the bottom insulation panel (Item 4) and the several details, exclusive of those found in the two removable access covers, which insulate the top, sides and ends of the heating platten core.

Side Insulation. The 2-inch thick Marinite panels shown in Figure 62 (Item 45 and 46) butt against the uppermost bottom insulation panel (Item 4) and the sides of the heating platten core. These two panels are held in position by the enclosure corner insulation blocks (Item 54, 55, 56 and 57) and the enclosure insulation retainer blocks (Item 50, 51, 52 and 53) shown in Figures 63 and 64, respectively. The corner blocks are installed in positions where mechanical damage could occur. The retainer blocks position adjacent to the corner blocks and also position and protect soft Spintex insulation from damage. The corner and retaining blocks are inserted between the side insulation panels and the sides of the aluminum-alloy enclosure box. They are tightly fitted to "wedge" the assembly together. The space between the retaining blocks placed at each side of the assembly is filled with 2-inch thick Spintex batting.

Top Insulation. The Marinite top insulation assembly (Item 58) shown in Figure 65 is a 2-inch thick panel to which five internal space blocks are cemented. During lay-up, two 2-inch thick Marinite spacers (Item 59, 60), shown in Figure 66, are placed at the ends of the top insulation assembly shown in Figure 65. These spacers "wedge" the top insulation panel between the heating platten core and the aluminum alloy enclosure box. The openings between the space blocks of the top insulation assembly are filled with cut and tightly fitted 2-inch thick Spintex batting.

End Insulation. The end insulation at the load support column end of the heating platten core differs from that at the stanchion end. This allows for the specimen assembly insertion into the heating platten core from the stanchion end.

At the stanchion end of the heating platten core, the enclosure end insulation (Item 49) shown in Figure 67, butts against the heating platten core. This insulation is held in place by the enclosure end filler (Item 48) shown in Figure 68. In the typical manner the filler "wedges" against the aluminum alloy enclosure box end to hold the insulation in place.

The enclosure end insulation (Item 62) shown in Figure 69 butts against the stanchion end of the heating platten core. The removable end insulation piece (Item 64) rests on top of the end insulation piece (Item 62) , and fits between the two side insulation panels (Items 45 and 46). Item 64 details are shown in Figure 70. The removable filler piece (Item 63) is identical to the end insulation piece (Item 64), and nests into the fixed filler piece (Item 47) which "wedges" between the end insulation and the aluminum alloy enclosure box end. The details of this end piece are shown in Figure 71.

Access Cover Insulation.* The access cover insulation consists of a sequenced lay-up of Marinite pieces. The lay-up is started by placing the top filler piece (Item 66, 75) shown in Figure 72, on the top portion of the inverted aluminum alloy enclosure box access cover. Then the access cover corner insulation blocks (Item 69, 70, 78, 79 shown in Figure 73) are placed in an upright position adjacent to the access cover sides. Afterwards the access cover end fillers (Item 68, 77 shown in Figure 74) are slid between the corner insulation blocks in an upright position into contact with the access cover ends. This is followed by access cover side insulation (Item 72, 73, 81, 82) shown in Figure 75 which is positioned upright and adjacent to the corner insulation. The lay-up is completed by placing the access cover end insulation (Item 71, 80 shown in Figure 76) in an upright position against the end fillers, and by laying the access cover top insulation (Item 67, 76) shown in Figure 77 flat on the top filler and pressing it home. The lay-up thus installed is clipped into position as described below (Figure 80).

Aluminum Alloy Enclosure*

The aluminum alloy enclosure box assembly shown in Figure 78 is used to contain the heater unit insulation and a heat radiation shield. The enclosure box is assembled from 6061-T6 aluminum alloy sheet and 6060-T6 aluminum alloy angles as shown. This box is provided with a flanged cover sheet which fits over the top of the heating platten unit and is bolted in place. The box cover is removable for convenience of assembly and access to the heater unit for repair or alteration. The ends of the enclosure box are provided with two access covers which are used to enclose spaces provided at each end of the heater unit for access to the specimen grip assemblies position adjacent to the heater unit. These covers are flanged and bolt into the enclosure box to provide complete enclosure of the

*See Also Section 2.

heating unit, specimen grips, specimens and instrumentation while tests are in progress. In Figure 79 an access cover insert is shown at the stanchion end of the assembly. This insert is provided and made removable to provide working space for charging specimen assemblies. The hollow box construction of the access cover insert and the hollow box closure at the load support column is provided for support of loose insulating material which packs the openings where the load transmission assemblies gain access to the heater unit. Figure 80 illustrates the fastening of insulation items to the access covers.

Power Supply

Single phase, 440-volt, 60-cycle current power is ued to supply heat to the heating platten unit. The apparatus used to distribute power to the several strip heaters is shown in Figure 81 along with those items required for Electrical Code compliance.

Input power first passes into a 60 ampere, fused safety switch to supply a 15-KVA, 440-220 volt stepdown transformer and branched into five circuits, each of which supplies current to a heating zone. Each heating zone includes eight or nine strip heaters, which are connected in parallel. The 220-volt supply to each heating zone is protected by a 25-ampere, 220-volt overload cut-out circuit breaker. Regulation of heat input to the strip heater banks is effected by 300-volt, 25-ampere, normally open relays which provide on-off control.

The regulating relays are actuated by 120-volt, 60 cycle current which energizes their electromagnet coils. These relays are controlled in their action by relays incorporated in each of the Barber-Coleman Model 392 indicating temperature controllers used to monitor temperatures in each of the heating zones.

The disposition of the individual heaters is shown in Figure 82. This diagram shows the arrangements which provide two end zones where heat losses are expected to be comparatively large. The two end zones are used to guard the two inner zones, each of which is used to heat a separate specimen gage length. The side and end heaters are combined to provide a thermal guard for the sides of the heating platten unit. The assymmetrical arrangement of heaters arises from the requirement for balancing inputs to the heater banks.

Temperature Control

The heating platten temperatures are sensed with No. 20 gage wire, chromel-constantan, thermocouple. These thermocouples are arrayed in the top of the heating platten as shown in Figure 83. The thermocouples shown are inserted through the enclosure box and the insulating material to enter 1/8-inch deep holes drilled into the copper heat distributor sheath. The temperatures sensed by these thermocouples are indicated by 0 to 800° F range Barber-Coleman Model 392 indicator-controllers containing the actuating relays to control the power inputs to the heater banks.

D. Specimen Temperature Measuring System

General Arrangement

The specimen temperature indication and recording system is comprised of seven components:

1. Temperature sensing thermocouples

2. Thermocouple leads

3. Selector switch unit

4. Junction box control unit

5. Cold thermocouple reference junction assembly

6. Thermocouple bucking assembly

7. Microvolt amplifier

8. Temperature recorder

The arrangement of these elements in the temperature measuring system is outlined in the block diagram of Figure 84.

Temperature Sensing Thermocouples. Premium grade, one-sixteenths inch diameter, Minneapolis-Honeywell Megopak thermocouples are used for temperature sensing. Megopak thermocouples used consist of paired No. 28 gage chromel-constantan wires packed in pure magnesium oxide granules retained in thin-walled Type 304 stainless steel tubes. The thermocouple hot junction consists of a welded bead joining the chromel and constantan thermocouple wires and fastening them to a stainless steel plug which is pressed into one end of the stainless steel sheathing tube. These thermocouples are made for prolonged use at elevated temperatures and are not subject to deterioration usually experienced with conventional thermocouple assemblies. The wires in these thermocouples are subject to aging from prolonged heating. In order to account for effects from thermocouple aging, each thermocouple is calibrated prior to use. At frequent intervals throughout single periods of use, the output of each thermocouple in use is compared with the output of a comparison thermocouple used only for comparison checking. The high thermoelectric output of chromel-constantan thermocouples amounting to about 0.043 millivolt per degree Fahrenheit is used to improve temperature sensing system accuracy.

Thermocouple Lead Wire. Premium grade, No. 20 gage, chromel-constantan, glass covered, duplex thermocouple wire is used to connect individual thermocouples to the selector switch and to connect the switch to the cold reference junctions. Connections to the switch are at a terminal board and independent of the internal wiring of the selector switch.

Selector Switch Unit. The selector switch unit providing selective connection of individual thermocouples with the temperature measuring portions of the system consists of a pair of solenoid-operated, rachet-driven rotary switches and a terminal board. The selector switch is actuated by automatic impulse switch installed in the temperature recorder. The switching system is powered with 24 volt direct current to avoid inductive disturbances in the thermocouple circuits. The selector unit is part of a Series No. 153 x 66 Minneapolis-Honeywell Eletronik Multipoint Logger System.

Junction Box Control Unit. The junction box control unit is independent of the temperature measuring parts of the system. It serves only for control of the selection of individual connections for measurement of thermocouple outputs. This unit is a control center providing the following selection and indication functions:

1. Indication of the specific group of twelve thermocouples being recorded at any time.

2. Omission of any bank of twenty-four points after that bank has been reached in a normal sequence of operation.

3. Permitting recycling of any pre-selected bank of twenty-four points after that bank has been reached in the normal sequence of operation.

4. Stopping the chart and printing system to allow continuous indication of any thermocouple output.

5. Permitting continuous recording of any given point by means of an automatic impulse.

6. Permitting manual advancement of point to point sequence by means of a manually operated switch.

Cold Reference Junction. The thermocouple cold junctions are made by crimping and hard soldering copper lead wires onto thermocouple leads. The positive thermocouple lead is connected to the voltage divider unit positive terminal. The negative thermocouple lead connects to the microvolt amplifier negative terminal. The lead from the voltage divider negative terminal connects to the microvolt amplifier positive terminal. The cold junction elements are immersed in a silicone oil bath which is held in a one-inch diameter by seven-inches long, rubber stoppered test tube. This test tube is positioned in a rubber stopper which fits into a one-liter Dewar flask filled with a crushed ice, distilled water mixture surrounding the oil bath. The bath is immersed to a depth of about five inches in the ice-water mixture. The Dewar flask stopper also accommodates the arm of a vibratory stirring device which forces convection in the ice-water and oil-bath media. For convenience, the cold reference junction assembly is set in a styrofoam block and the stirring head is mounted to an adjacent bracketry.

Voltage Divider Unit. The voltage divider unit provides millivoltage for cancelling the major portion of the thermocouple output. The purpose of this is to reduce the output millivoltage to values within the range of the microvolt amplifier. In use the voltage divider unit is set to the output of the thermocouples at the temperature desired, and serves the dual purpose of providing a reference voltage with which thermocouple outputs can be compared and a reference with which the differences in output of thermocouples can be compared. A schematic wiring diagram of the voltage divider unit is shown in Figure 85.

Microvolt Amplifier. A Leeds and Northrup No. 9835-B stabilized, direct-current microvolt amplifier receives different potential outputs from the thermocouple-voltage divider combination and amplifies this small voltage. The amplifier provides input for the millivolt recorder connected with the amplifier. The microvolt amplifier accepts up to five millivolts input across five hundred ohms resistance corresponding to any input range for recorder preamplification. The amplifier normally operates in the minus to zero to plus twenty-five microvolts output range. It is provided with factor controls for providing 1, 2, 4, 10, 20 and 40 times magnification. The amplifier has a self contained power unit and operates on 115 volt, 60 cycle alternating-current.

Temperature Recorder. A Minneapolis-Honeywell Model 153 x 64, twelve point fixed time cycle, electronic, strip chart recorder indicates and records amplified difference potentials. It records in the minus to zero to plus five millivolt range. Thermocouple outputs are observed in potential units, thus temperatures are taken from conversion charts. The recording unit is the electronic null-balance type and automatically corrects against a standard reference cell for maintenance of one fifth of one percent of full span accuracy.

The recorder's electronic circuit and chart drive operate on 115 volt, 60 cycle alternating current. The automatic impulse switch actuating the external switch for multi-point recording is included in the recorder and is synchronized with the chart drive.

E. Strain Measurement System

The system for detecting creep strains of very small magnitude for onset of creep stress measurement consists of two Kavlico Electronics, Incorporated, Model GM 2105 systems. Each system contains nine individual linear transducer strain measuring assemblies and an instrument cabinet which contains the electronic apparatus necessary to the operation and reading of the transducer elements. For use the transducers are attached to test specimens and are connected to the cabinet assembly by lead-wire harnesses. Electrically, each system includes a precision oscillator, nine demodulator and filter assemblies, nine voltage comparator and microdial readout assemblies, a null indicator-demodulator assembly and the nine transducer assemblies. Figure 86 schematically shows the functional arrangement of the assemblies comprising a strain measuring system.

Transducers. Linear variable differential transformer transducers are used in the strain measuring system to translate the displacement of a magnetic core into an alternating current voltage which is porportional to the displacement. A differential transformer usually consists of one primary and two secondary, hollow, cylindrical windings. The primary winding is at the center of the winding cylinder, and the two secondary windings are arrayed adjacent to each of the two ends of the primary. The windings are totally enclosed in a double-walled metallic cylinder and the magnetic core is inserted into the cylindrical channel in the center of the winding assembly.

When an alternating current is fed through the transducer primary, the transformer core inductively couples the transducer primary with its secondary windings. Centering the transducer core in the winding assembly so that an equal portion extends into each secondary results in equal inductive couplings between the primary and each of the secondaries. This results in the induction of alternating voltages of equal magnitude in the secondary coils. The secondary coils are connected in series opposing arrangement, and thus the voltage induced in one secondary opposes that induced in the other secondary. In the centered position the secondary voltages theoretically cancel each other so that the transducer output is zero volts.

When the transducer core is centered in the windings, the position is called the null position, and the output voltage which appears at this position is the null position, and the output voltage which appears at this position is the null voltage. Practically, the null voltage cannot be zero because perfect electromagnetic symmetry and total absence of capacitive coupling between the windings is required. Also at null position the voltages in the secondaries have different amounts of harmonic distortion, and this also prevents complete voltage cancellation. Symmetry and capacitive coupling effects cannot be entirely eliminated, but they are miminized by careful design and manufacture. Harmonic distortion correction is effected by the insertion of carefully designed and built capacitive networks in transducer circuits.

When a transducer core moves to either side of null position, the inductive coupling between the primary and one secondary coil is increased, and the coupling between the primary and the other secondary coil is decreased. Thus the voltage in one secondary is greater than that in the other, and because the two secondaries are connected in series opposing arrangement, the output voltage is the difference between the two secondary voltages.

The phase angle between primary and secondary voltages is important in movable core transducers because phase shifts inherent to construction are present along with phase shifts which change in relation to the amount of core displacement. A constant phase shift characteristic of construction can be compensated by shunting the secondary windings with capacitors. The variable phase shift associated with core position changes cannot be corrected with external circuitry, and minimizing this effect requires care in design and construction. Also since the phase shift characteristics of differential transformers relate to the frequency of the alternating current input to the transducer, the choice of frequency is a matter of design optimization, and frequency stabilization in alternating-current voltage sources is important.

Ordinarily alternating-current voltage fluctuations are not of great importance in null seeking servo systems, but in transducers used for measurement, alternating-current voltage stability is important in the reduction of measuring error. For this reason great care is required in providing very well stabilized alternating-current voltages for operating differential transformer systems.

In addition to the above factors, the linearity, sensitivity, load impedence and shielding are important to good transducer operation. In the main, the management of these factors depends on good design and experience.

The differential transformers used in the Kavlico systems have, as a result of the considerations discussed, the following characteristics.

Transducer Characteristics

Excitation	22 volts, 800 cycles per second
Stroke	± 0.050-inch
Linearity	± 0.5 percent
Sensitivity	68 volts per inch
Input Impedance	300 ohms minimum
Output Impedance	200 ohms maximum
Null Voltage	25 millivolts maximum
Phase Shift	3 degrees maximum
Dimensions	See Figure 87.
Maximum Operating Temperature	275 degrees Farenheit

Electronic Instrumentation

The electronic instrumentation enclosed in the instrumentation cabinet, exclusive of the transducers, is schematically diagramed, with reference to electrical function in Figure 88. The alternating current power supply includes a Behlman-Invar Electronics Corporation single-phase, 0.1 percent tolerance fixed-frequency oscillator which supplies signal input to a Behlman-Invar Electronics Corporation Model 161A Invertron low tolerance, voltage regulated power supply. The output from the power supply is fed as 22-volt, 800 cycle alternating current into the transducer primaries and into a bridge rectifier, voltage divider-control assembly provided by Kavlico Electronics, Incorporated.

The alternating-current voltages developed in the transducer secondaries are demodulated by a bridge rectifier arrangement and the difference output is fed into a Hewlett-Packard Company No. 413A direct-current null voltmeter. From the null voltmeter the direct-current is fed into Beckman Instruments, Incorporated, Model A, high resolution, multi-turn Heli-pot potentiometers for readout adjustment, and into Clarostat Manufacturing Company, Incorporated Model 412-462, micro-adjusting and reading high precision potentiometers for precise sensitivity adjustment. From the potentiometer circuits, the direct-current return leads to the voltage divider to close the circuits.

The system characteristics are tabulated below. In order to provide maximum accuracy and resolution, the null balance readout has two ranges.

System Characteristics

Range A

Range	0 - 0.030 inch
Accuracy	0.0003 inch at constant temperature
Resolution	0.00003 inch

Range B

Range	0 - 0.003 inch
Accuracy	0.000030 inch at constant temperature
Resolution	0.000003 inch

The operation of the system is as follows:

1. Attach transducer to the test specimen.

2. Heat the transducer and test specimen to desired temperature.

3. Apply load.

4. Null the transducer and measure creep strain.

The operating and maintenance instructions for the two Kavlico Electronics, Incorporated linear displacement indicator systems are given in Appendices A through D.

F. Strain Gage Attachment Fixtures

The strain gage attachment fixtures, which implement gage length measurements, provide fixed point contact between test specimens and strain gaging apparatus at each end of specimen gage lengths. In addition, these fixtures secure the strain gaging apparatus onto specimens by means of built-in clamping arrangements. Auxiliary rollers are provided in clamping pieces to aid contact points in securing fixtures onto specimens. These rollers allow the contact points to remain stationary with respect to the specimen while expansion of the fixtures occurs during heating. Austenitic stainless steel (Type 303) is used in the fixtures to reduce electromagnetic disturbance of strain gage transducers.

Each strain gage attachment fixture assembly includes the following components:

1. Transducer holders

2. Adjustment fixtures

Transducer Holders*

Each transducer holder assembly consists of a transducer holder and a clamp. The transducer holder body is shown in Figure 89. In assembling a transducer holder, a roller pin (Figure 100) is polished so that its mating roller (Figure 95) is free running on it and the pin able to easily slip into the lateral 1/16-inch diameter holder holes shown near the top of Figure 89. The roller is assembled into the holder by pinning the roller between the tines of the fork shown uppermost in Figure 89. The next step consists of inserting 3/16-inch long steel record playing needles in the vertical 1/16-inch diameter holder holes at the lower end of the holder's tang shown just above the center of Figure 89, and clamping them with the No. 0-80 (1/16-inch diameter) set screws angled in at 45-degrees. Needle adjustment is accomplished by placing the assembly on a flat plate, inserting a 0.050-inch thick shim under the lower fork shown in Figure 89, pushing the pins into contact with the plate, and drawing the set screws as tight as possible with an Allen wrench. The transducer next is inserted between the lower tangs shown in Figure 89 so that the lead wires are up and leading to the top of Figure 89. The inserted transducer is positioned so that the innermost No. 0-40 (1/8-inch diameter) set screw just engages adjacent to the inserted transducer end. Holding the transducer holder on a flat plate with a 0.050-inch thick shim underneath the lowermost tines shown in Figure 89, the transducer is bottomed and levelled on the shim and clamped in with the set screws.

*See also Section 2.

In assembling the transducer holder clamp it is necessary first to make sure that No. 6-32 assembly screws run free in the tapped holes shown in Figure 90. Re-tapping may be necessary, but it is essential that free running screws be provided to permit "feel" when assembling the clamps on specimens. The assembly of the transducer holder clamp rollers and contact points follows that used for the transducer holders.

The preceding assembly steps result in two permanent sub-assemblies. In assembling these together on a specimen, the transducer holder is positioned near the center gage mark with the transducer leads facing the center of the specimen. Two No. 6-32 by 7/8-inch long screws are inserted into counter-bored holes adjacent to the transducer, and two No. 6-32 by 5/8-inch long screws are inserted in the holes nearest to the roller. Then the transducer contact points are "felt" into the scribed gage length marks. Next the transducer holder clamp is brought under the blocked up specimen and the four screws are engaged. Holding the transducer holder and its clamp with the thumb and finger of one hand, the two assemblies' contact points are brought into contact with the specimen at the gage mark lines, where with the screws are run up so that contact points engage the specimen and rotation of the rollers is just possible. Finally the screws are snugged-up with light finger pressure on a small screwdriver. Excessive tightening of assembly screws will cause the contact points to "pop" loose and result in fixture wobble. When this occurs it is necessary to disassemble, reset points, and reassemble.

Adjustment Fixture Assembly*

Adjustment fixture assembly consists of first assembling the adjustment fixture screw holder (Figure 93) to the bottom end of the adjustment fixture body (Figure 91) with tightly drawn No. 6-32 by 7/16-inch long screws. Next the adjustment fixture push rod guide (Figure 94), in the position shown in Figure 94 and on the same side of the fixture body above which the screw holder projects, is attached with No. 6-32 by 5/8-inch long screws threaded and tightly drawn into the tapped holes provided in the body. Afterwards rollers and 1-inch long contact points are installed as described above in transducer holder assembly.

After contact points are installed, push rod couplings (Figure 97) are threaded onto the 5/8-long thread of the push rod (Figure 101) to the full depth of the thread. The transducer core is provided with a No. 4-40 brass lock nut which is run to the end of its thread preparatory to inserting the core into the push rod coupling. In positioning the transducer core, adjustment must be made to permit at least 3/16-inch of thread to remain exposed between the end

* See also Section 2.

of the transducer core and the brass locking nut which is tightened against the push rod coupling. This adjustment is necessary to allow the transducer core to enter the transducer far enough for mechanical nulling.

After the push rod is assembled to the transducer core, its remaining threaded end is passed through two push rod supports (Figure 96) and the push rod guide from the side opposite the adjustment screw holder. When the push rod emerges from the guide about 3/16-inch, a 3/16-inch diameter by 1 3/8-inch long compression spring is placed on the push rod. Holding a small piece of clad aluminum sheet against the contact pins the spring is raised and a No. 6-32 nut is placed between it and the piece of aluminum sheet, and the nut is pushed down and engaged with the push rod, whereupon the aluminum piece is removed. In push rod assembly it is necessary that push rod ends be squared and freed from burrs to permit smooth contact between the push rod end and the end of the adjustment screw. Following this, the transducer core is inserted in the transducer, the contact pins positioned, and the adjustment screw holder assembly is assembled with the screw holder assembly clamp onto the specimen in the same way the transducer holder was assembled onto the specimen. The assembly of the fixtures onto the specimen is completed by inserting and pinning the push rod support rollers (Figure 97 and 98), and fastening the push rod supports to the push rods with the set screws provided.

The assembly of the adjustment screw holder clamp (Figure 92) is not detailed since its assembly is the same as the transducer holder clamp assembly. The adjusting screws consist of nine 5-foot and nine 6-foot long piece 1/8-inch diameter Type 303 stainless steel rod provided with 2-inch lengths of No. 6-40 thread on one end. Upon completion of fixture attachment these screws are threaded into the adjustment screw holder, brought into contact with the push rod, and the transducer core is run into the transducer until the end of the core enters completely to a depth of about 1/8-inch.

Fixture Adjustment*

Upon completion of assembly as described above, it is necessary to connect each transducer with its appropriate readout unit and to effect a mechanical null as described in Appendix A or C. It may be necessary in order to effect the mechanical null to adjust the emergent length of the transducer core thread at the end of the push rod coupling. In making this adjustment care must be taken to keep the spring retaining push rod nut from binding against the contact point pins. During adjustment it also is necessary to make certain that the transducer is not "cocked," since this will induce binding. In some cases it may be necessary to file the flats of the spring retaining nuts to permit their free

*See also Section 2.

operation. Any tendency for the transducer core lock nut to press against the transducer must be avoided at all times to preclude wedging action between the two attachment sub-assemblies, otherwise the contact point pins will loosen. When this occurs reassembly of the fixtures to the specimen is required.

G. Specimen Attachment

Attachment of specimens to test machine specimen grip assemblies (Figure 29 and 30) is effected with attach straps shown in Figure 102. Four straps are used at each end of a specimen, two above and two below, and are attached with the pins shown in Figure 103. These pins are inserted so that the threaded portion faces the transducers attached to specimens. They are secured with lightly drawn AN-316-8 (1/4-inch thick) nuts.

The attachment of straps to specimen grip assemblies is effected with the 3/8-inch diameter pins and clamping pieces shown in Figures 29 and 30. In attaching the specimens to the specimen grips it is essential that any specimen rotation or twisting be avoided. This means that the 3/8- and 1/2-inch pins used in the specimen grips must be finger tightened, otherwise contact pin breakage or slippage will occur to cause strain gage malfunction.

H. Specimen Transfer Arrangement

To prevent disturbance of strain gaging instrumentation when instrumented test specimen assemblies are moved from the supporting blocks on which they are assembled, the distances between the contact pins are first measured to the nearest 0.001 inch with a 24-inch vernier caliper. Then the specimen assembly support shown in Figure 104 is lowered over the specimen assembly which includes strain gage fixtures, adjusting screws and attachment straps. After positioning the support, the attaching straps and adjusting screws are blocked and taped to the support. Then a 2- by 2-inch by 8-foot stick of wood is taped to the supported specimen assembly. The support's set screws are drawn snug and the build-up is turned over preparatory to readjusting the attachment strap set screws for transfer to the testing machine.

When the specimen is in position at the testing machine, the asbestos wrapped transducer lead plug is attached to a No. 14 soft wire drawn through the desired heating platten channel, and "snaked" into the recess. As the plug is drawn, and lead wire slack is taken up the freed specimen support and instrumented specimen is slid on the 2- x 2-inch stick into the heating platten recess. As the support enters the recess and interference appears imminent, set screws are removed. Slow feeding of the support into the recess by handling only the support is essential to the feel required for detecting contact of the adjusting screw with obstructions.

Rough handling in charging specimens will result in contact point slippage or breakage which necessitates withdrawal and reassembly of the specimen array. In any event after specimen insertion and attachment is finished, check should be made to assure freedom of adjusting screw rotation and attachment, tightness. Any contact point slippage or breakage is readily detectible in attempting to gently "wiggle" the adjusting screw in a longitudinal direction. Specimen transfer is completed by attaching the attach straps to the specimen attach grips and packing macerated asbestos into the heater recess to complete the seal between the specimen assembly and the heater recess. This packing is done by finger pressure, and enough packing is used to fill at least two inches of the recess length.

I. Creep Test Procedure

The initial step in test performance consists of replacing, fastening and sealing the fastened heater end covers with macerated asbestos. At this time the five temperature control instruments are set to the desired temperature and the power is turned-on at the main switch. Then the specimen temperature indicating thermocouples are positioned in contact with the test specimens by lowering them from their retracted position. To insure positive contact the weights provided for holding these thermocouples down are attached to their exposed portions.

When the heater has attained the temperatures set on the control instruments, temperature adjustments are made as required. A temperature check is made by first charging the cold junction receptacle with ice and allowing its temperature to stabilize. Stability is indicated by the attainment of freezing temperature by means of an immersion thermometer. When cold junction stability is obtained, the specimen temperature indicating system is energized by turning the junction box power control switch on. In the determination of the specimen temperature indication, the thermocouple array is cycled at least five times to obtain sufficient record to detect possible malfunctions in multipoint recorder indications. When the temperature indication survey is completed the indicated millivoltages are corrected for thermocouple error reflected in calibration. The corrected readings are used to gage the amount of adjustment required in the temperature controller settings, and after each adjustment surveys of the specimen temperature indicating thermocouples are made to determine the suitability of the adjustment. Resurveys are made as required at four-eight or sixteen hour intervals.

When the heater and specimen temperatures are satisfactory, the strain gaging instrumentation is attached to the transducer leads, and mechanical and electrical nulling is accomplished as indicated in Appendix A and C.

Subsequent to nulling the strain gages, the lever arms are levelled. This step requires adjustment of the position of the lever arms by adjusting the pull rod turnbuckles. The purpose of this levelling is to bring the lever arm to such position after it is loaded that the vertical center line of the fulcrum pivots remain within 15 degrees of the vertical position. This positioning is required to minimize effects of lever rotation upon weight application.

After levelling, hydraulic jacks are placed under the levers adjacent to the weighing pans and extended just enough to pick up the weight of the lever arm.

Then the weights are placed on the weight pan, the jack's relief valve is barely cracked and the weights are allowed to settle as slowly as possible in applying force to the specimen. As soon as the weights have settled, the transducers are connected again for the duration of the test run, and mechanically nulled.

Preliminary creep testing indicates the primary creep phase to be of short duration (twelve to forty minutes) in the stress regions under investigation at various temperatures. Thus to closely estimate the start of secondary creep, if any, initial strain readings are made at 1/2, 1, 2, and 4 hours subsequent to loading. Thereafter strain readings are obtained at the eighth and sixteenth hour of each day.

At the end of each test run, the weights are lifted by means of jacks placed under the lever arms and then are removed from the weight pans. Next the transducers are disconnected and the strain gage instrumentation and temperature indicating thermocouples are moved out of the way. The power is then turned off and the heater is opened at both ends. The nine transducer plugs that are removed through heater recesses are asbestos wrapped and withdrawal of the specimen assembly support with the instrumented test specimen is accomplished. To prevent damage to the test specimen or its instrumentation, the assembly is slid onto a wooden 2- x 2-inch stick for transfer to the assembly bench. Here the specimen assembly supports and the specimen assemblies are placed on blocks to cool. When cooled the supports are removed, the strain gaging apparatus removed from the specimens by removing the eight screws which attach clamps to the transducer holder and adjustment fixtures. At this time the fixtures are inspected and reconditioned as required preparatory to the succeeding test.

J. Calibration Procedures

Loading System Calibrations

Loading system calibrations are done with the dynamometer sketched in Figure 105. The dynamometer body shown is made from a 5/8 x 1 3/4 x 72-inch piece of 4130 steel plate. Prior to machining the dynamometer blank was normalized at 1650°F for two hours and air cooled. After normalizing it was stressed to 100,000 psi stress three times to establish a cold worked pseudo-elastic limit in it. After stretching the piece was double tempered by heating at 750°F for two hours and air cooling two times, and then machined. In machining the contours shown in Figure 104 were established and provided with RMS 64 or better finish by profile milling. After machining the reduced sections of the dynamometer were hand polished to RMS 32 or better finish preparatory to strain gage attachment.

After dynamometer body preparation was finished, Baldwin-Lima-Hamilton Type FABX-25-12-S6 rosette electrical resistance strain gages were applied at the center of each reduced section of gage length. To obtain desired averaging, gages were attached both to the top and bottom surfaces of the dynamometer. Baked Epon VI (Shelf Chemical Company) adhesive was used for gage attachment. After assembly the dynamometer was calibrated in a 400,000 pound capacity. Baldwin hydraulic universal testing machine. This testing machine was accurate within plus or minus one-half of one percent as shown by calibration with Morehouse proving rings.

In the design and construction of the creep frame, counterbalance provisions for the lever arms were not made in order to simplify lever construction. Counterbalance provisions were introduced as a first calibration step. In accomplishing this, 5/8 x 1 3/4 x 72-inch steel bars were steel strapped to the lever arms so that they projected rearward from the weight carrying end of the lever arms. Next steel rollers were placed under the specimen attachment fixtures and the load transmission assembly was brought to static balance by sliding 25-pound lead pigs along the projecting steel bars until critical balance was found. When initial balance was effected, the steel straps used to secure the pigs onto the steel bars were snugged-up. At this stage the dynamometer was fastened into the specimen grips with the aid of attachment straps, the Baldwin-Lima-Hamilton Model 120 strain indicator was connected to the strain gages, and a condition of balance was obtained by adjusting of the lead pig position for a no-load strain gage indication in each load transmission assembly.

Early in calibration it was found that slots provided in standard weights to permit their centering on weight pans resulted in imbalance which caused side thrust in the lever arm fulcrums. This source of error was removed by cutting the weight hanger tie rods (Figure 14) and inserting 6-inch lengths of Rex No. 60 roller chain in them to allow the weights to pull downward. As initial calibrations proceeded, it was evident also that the circular seats in the lever arm bearing pads (Figure 36) allowed some front-to-rear movement of the lever fulcrum pivots. This adversely affected calibration repeatability, and to overcome this, pads with 0.094-inch by 140-degree included angle vee-slots were made and installed in lieu of the circular seat pads.

Throughout calibrations and succeeding loadings, precautions are taken to preclude the introduction of loading force variations arising out of lever rotation effects. Initially the distances from the top of the load support column and the bottom of the lever arm at reference points representing the condition of verticality of the fulcrum pivot center line were ascertained. From this information position gages were prepared for use during load applications. During each load application the position of the lever arm is maintained by gradual adjustment of the transmission assembly turnbuckles as required to obtain the proper relation of the lever with respect to the position gage.

Calibrations show that when the foregoing precautions are taken, the repeatable loading accuracy of the machine is within the plus or minus one-half of one percent required in testing machines.

Temperature Calibrations

The temperature indicating system is intended to provide continuous calibration of the heating effectivity of the heating unit. This is accomplished by the use of 45 thermocouples which are inserted into the top of the heating unit and penetrate through it to come into contact with the test specimens positioned in the several heating unit channels. The portion of the heating unit that is kept under calibration scrutiny is the central 30- by 40-inch area lying at the mid-thickness plane of the heating unit.

The heating accuracy was found to be markedly influenced by the condition of the Marinite insulation material used in its construction. This material shrinks considerably when it is initially heated, and as a consequence of this openings between the insulation and the enclosure box are created. These slot-like openings act as flues and tend to draw cold air in at one end of the unit and expel it at the other. This flue effect will cause one end of the calibration area to work hotter than the other. To reduce these flue effects it is necessary that whenever the enclosure-box is opened the ends of the heater unit be closely inspected for the presence of gaps in the insulation or between the insulation and the heating unit or the enclosure box. Where gaps appear, they must be closed with tamped-in macerated asbestos packing.

Calibration requirements also necessitate plugging the specimen insertion channels at each end with macerated asbestos to negate flue effects at these points. Inasmuch as wadding around the transducer core adjusting screws is necessary, care must be exercised to avoid strain-gage instrumentation disturbance. Shrinkage of the macerated asbestos in drying is sufficient to provide freedom of movement of the adjusting screws.

Heat conductance in the load transmission assemblies also tends to influence temperature calibrations. In order to reduce this heat loss, those portions of these assemblies that lie within the enclosure box, also are packed in macerated asbestos prior to sealing the enclosure. After sealing the enclosure, the anchor nuts, bearing plates and tension rods at the stanchion end of the test frame are packed in macerated asbestos.

To further preclude flue effects, all the enclosure-box access-cover joints are gasketed with asbestos sheet material in assembly and are packed with macerated asbestos after assembly is complete. In this packing the macerated asbestos is applied to completely cover the aluminum alloy angles used to retain the assembly bolts, and to plug openings where load transmission assembly details emerge from the enclosure box.

In the presence of flue-like gaps in the heater unit, the enclosure-box acted as an effective heat radiator causing room temperatures to rise as high as 115°F. To reduce this temperature which was not considered beneficial for associated electronic temperature and strain measuring apparatus, the entire heating unit was covered with a layer of 2-inch thick fiberglass insulation batts and a 1-inch thick fiberglass-aluminum foil blanket. This insulation cover reduced the room temperature to about 90°F., and is retained for the benefit of the electronic apparatus.

When the precautionary steps mentioned are observed, the heating unit will maintain temperatures within the specimen heating zones within plus or minus 1°F of desired temperature in the intended range of operation (450 to 650°F).

Strain-Gage Calibrations*

Differential transformer, electrical transducer strain gage calibrations are made with transducer assemblies held at 550°F. The object of the calibrations

*See also Section 2.

is to relate the voltage output of the individual transducer to linear displacement as measured by means of micrometer arrangements. In these calibrations the full strokes of the transducers are considered, but in test use only the central 75 percent of the stroke is considered useable for strain gaging purposes. This precaution avoids the effects of non-linearity known to be present when extremes of transducer stroke are encountered. The calibrations are carried out with micrometers checked to 1/10000 inch accuracy by Johannsen blocks.

K. Creep Test Specimen

The creep test specimen for onset of creep stress measurement is shown in Figure 106. This specimen is profile milled from 0.050 x 1 3/8 x 60-inch sheared sheet metal blanks. In order to preserve alignment of specimen pin holes, tooling reference holes and reduced section edges, all holes are located and drilled in a first milling machine operation preparatory to fixturing for the profiling operation. In profile milling, the specimen edge finish is held to RMS 64 finish, and after milling the reduced section edges are polished with No. 320 grit abrasive paper.

In machining minor differences in the widths of the two tandem reduced sections are anticipated. For this reason gage length section areas will show minor but significant differences which must be taken into consideration in loading, since the stresses in the two gage lengths will vary somewhat. When loading schedules are planned, loads suitable for applying intended stresses are calculated for only one gage length section. After this load has been established, the stress on the remaining gage length is found from the known load and area. In reporting test data, actual rather than nominal stresses are reported.

2 REVISION OF CREEP TEST MACHINE CONSTRUCTION AND OPERATION

A. Introduction

During the initial tests with titanium alloys the transducers procured for elevated temperature use malfunctioned after about 250 hours of successful prior trial. Erratic behavior of the units after about 50 hours of test use developed into non-responsiveness in the majority of cases at about 80 hours of test. Mechanical adjustment checks followed by electrical continuity tests verified the presence of many open circuits in the transducer connections.

Faulty unit dissection eventually showed that the solder connections between the winding terminals and lead wire terminals had failed. Prior successful use of transducers of this kind in similar applications and the lack of detectable solder discrepancy failed to provide ready answers to the difficulty. However the press for pertinent data did not permit extensive search for the cause of trouble, and it was surmised that the 300 plus hours of elevated temperature exposure had given rise to the diffusion of solder constituents into the fine copper wires used, and that resultant intermetallic compound formation eventually brought on the joint failures. This surmise indicated a desirability for instrumentation which would operate reliably at room temperature for very long periods of time. Accordingly, the defective instrumentation was replaced with room temperature apparatus, and this change required the equipment and procedure revisions noted in this section.

B. Apparatus and Procedure Revisions

The apparatus revisions required to permit use of room temperature electrical transducer strain gages included:

1. Modification of nine load transmission assembly arrays and attachment straps.

2. Modification of heater unit access covers.

3. Revision of strain gage attachment fixtures and the provision of reach rod arrangements for these fixtures.

Load Transmission Assembly Array

The load transmission assembly array modifications made provided the free space required for placement of transducers, transducer retainers and zero adjustment knobs. This required repositioning the center lines of transducers above and parallel to specimen center lines. Space limitations within the heating unit channels restricted vertical displacement of transducer centers to slightly over one-half inch above the specimen surface. Insulation thickness in the end covers required that the transducers be positioned at least 4 1/4 inches out and away from the end of the unit.

Space in the load transmission assembly array was provided by:

1. Removing the Type J Boston Gear Co. Universal Joints (nine pieces) shown in Figure 30.

2. Discarding the specimen grip plates (18 pieces) shown in Figures 29 and 30.

3. Discarding the AN6-11 bolts (18 pieces) shown in Figures 29 and 30.

4. Removing the heads from the AN8-11 bolts (18 pieces) shown in Figures 29 and 30, and drilling 1/16-inch diameter cotter key holes in the shank ends of these bolts. Cotter key holes were centered 1/8 inch below the tops of the bolts and drilled on the diameters. Each bolt also was provided with a 1/16-wide by 1/8-inch deep driving slot milled on diameters. The threads on each bolt were lengthened to permit running them into the specimen grip bodies enough to snug the cotter keys against the specimen attach straps which are attached with cut-down bolts.

5. Lengthening the step on the specimen grip body (Figure 32) from 1 1/8 inches to 5 1/4 inches by milling.

6. Discarding the specimen attach straps (72 pieces) shown in Figure 102, and replacing them with 36 straps with holes spaced on 30-inch centers and 36 straps with holes spaced on 24-inch centers; other dimensions, except overall length, remaining as shown in Figure 102.

Heater Unit Access Covers

Heater unit access cover modification was accomplished by first removing the insulation (see Page 17 and Figure 80) and then re-working the access cover shell (Figure 78) to Figure 107 requirements. The following steps were then taken in cover insulation re-assembly:

1. A 6-inch deep by 39-inch recess, centered on the 39-inch dimension, was made in each of the Item 66 and 75, Figure 72 access cover top filler pieces. One of the two resulting U-shaped pieces was laid in each of the two shells so that one filler piece surface was in contact with the inner, U-shaped metal shell surface.

2. The access cover corner insulation pieces (Items 69, 70, 78 and 79, Figure 73) were replaced in the U-shaped cover shell recesses. One piece was placed in each recess so that one 2 by 10 -inch surface contacted the top filler piece and one 5 5/8 by 10 inch surface contacted the outer wall of the cover shell recess.

3. The side insulation pieces (Items 72, 73, 81 and 82, Figure 74) were replaced in the U-shaped cover shell recesses. One piece was placed in each recess so that one 2 by 8-inch surface contacted the top filler piece and one 5 5/8 by 8-inch surface contacted the inner wall of the cover shell recess.

4. The two access cover end insulation pieces (Items 71 and 80, Figure 76) were placed in one cover shell. The first installed was placed against the front wall of the cover shell with its 2 by 39-inch flat surface in contact with the top filler piece. The last installed was placed against the one first installed. Its 2 by 39-inch surface also was in contact with the top filler piece. Two pieces similar to Items 71 and 89 were made and installed in the other cover shell in the same manner.

5. The access cover end filler pieces (Item 68 and 77, Figure 75) were placed in the remaining recesses in the end cover lay-up so that the flat 2 by 43-inch surface contacted the top filler piece.

6. The retaining bolt holes were then drilled into the insulation at locations originally established. A counter-bore was made at each emergent bolt hole inner end. Nuts and washers were drawn into these recesses which then were packed with macerated asbestos to complete the reassembly.

Strain Gage Attachement Fixtures

Strain gage attachment fixutre revision provided reach rod arrangments for transmitting deformation indications from specimen gage lengths inside the heating unit to the heating unit exterior. Means for supporting the transducers outside the heating unit were also provided in the rearrangement.

Reach rod assemblies consist of 1/8-inch diameter cold-drawn Type 303 stainless steel rounds which are inserted into a 3/8-inch outside diameter (0.157-inch inside diameter, 0.109-inch wall thickness) Type 304 stainless steel tube to provide a concentric and telescoping arrangement for transmitting differential motion. Each end of the 1/8-inch rounds is threaded; one end with about 1 1/2-inches of No. 4-40 thread for receiving the transducer core, and the other with about 1 3/4-inches of No. 6-40 thread for insertion in the adjustment screw holder (See Page 29 and Figure 93). Each 1/8-inch round is 49 inches long. Each 3/8-inch diameter tube is 39 inches long and is provided with a 5/8-inch length of No. 3/8-18 thread on one end to receive the transducer retainer. In order to accomodate these tubes, the transducer holders (see Page 28) were modified. This modification consisted of the drilling and tapping of two additional 1/16-inch diameter set screw holes in the holder shown in Figure 89. These holes are positioned as shown but were made in the un-drilled tine shown in the top view of Figure 89. Provision of additional set screws allows full clamping of 3/8-inch tubes which are inserted between holder tines. To provide support and location for the 3/8-inch tube, 3/8 by 3/8-inch slots also were milled in the centers of the tine supports.

Details of the transducer retainer are shown in Figure 108.

Strain Gage Attachment Fixture Assembly

The assembly procedure described below supplants that described on Pages 29, 30, and 31. In revised procedure the transducer holder and transducer holder clamp assembly proceeds as described on Pages 28 and 29, and the adjustment fixture assembly and adjustment fixture clamp assembly proceeds as described in Paragraph 3, Page 29 and Paragraph 2, Page 30. In the present procedure, strain gage attachment fixture assembly is accomplished entirely during test set-up. The assembly steps are as follows:

1. Specimen Preparation. The specimen ends are marked F (front) and R (rear) and centers are then located and scribed. Next, a scribed line 4 inches to the rear of the center and a scribed line 3 1/2 inches to the front of center are located and made.

2. Adjustment Fixture Attachment. Adjustment fixture attachment involves placing the front fixtures atop the specimen with their roller facing the F end of the specimen, and their contact points against the specimen at the lines scribed 3 1/2 inches away from centers. Four No. 6-32 by 5/8-inch long screws are then placed in each fixture. Adjusting screw fixture clamps with their rollers facing the F ends, and with contact points up are then engaged with the No. 6-32 screws projecting downward. Where the screws are fully engaged the fixtures are "felt" into position by noting the engagement of the contact points with the scribed one. When engagement is obtained, the clamping screws are tightened. The assembly of the rear fixture is the same as described, except that the adjustment fixtures and adjustment fixture clamps face to the rear and their contact points engage the lines scribed 4 inches away from the centers.

3. Transducer Holder Attachment. Transducer holder attachment involves placing the front holders atop the specimen with their rollers facing to the R end of specimens, and their contact points against the specimens. Placements are made about 20 inches forward of the adjustment fixtures. The two 7/8-inch and two 5/8-inch long No. 6-32 screws are next placed in the holders. The transducer holder clamps with their roller facing to the R end, and their contacts points up are then engaged with the downward projecting No. 6-32 screws. When these screws are engaged and the holders and clamps are snugged enough to just permit sliding the assembly, gage length settings are obtained. This is done with a 24-inch vernier caliper set for a 20.000-inch inside measurement. Desired distance is obtained by placing the caliper against the contact point indicating shoulders of the adjustment fixtures, then bringing the transducer holder contact point indicating shoulders into contact with the extended caliper finger just before tightening the clamping screws.

4. Reach Rod Assembly. Reach rod assembly is started by tightly threading transducer cores onto the 1/8-inch diameter round, threading transducer retainers onto the 3/8-inch diameter tubes, and inserting the rod into the tube ends which carry the retainers. These assemblies are placed in the transducer holder slots and the threaded rod ends are passed through the reach rod supports to engage in the adjustment fixture threads. All but about 3/16-inch of the thread in the rods are run

into the fixtures. The transducers are then seated in their retainers and fastened with the set screws provided. The tube positions are adjusted by sliding so that the transducer cores are inside and about 1/8 inch in from the end of the transducers. At this point the transducer holder set screws (4) are drawn up to lock the rods in position. Assembly is then completed by running brass lock nuts onto the transducer cores, threading on the adjusting knobs, and locking the cores with the nuts.

After adjusting transducers as described, the instrumented specimens are ready for installation in the testing machine. The completely instrumented specimen can be installed if the heating unit is cold. If the furnace is hot, it is necessary that the rear transducer core adjusting knobs, nuts and transducers be removed to prevent heat damage to the transducers. In this case the assembly is completed subsequent to specimen installation in the testing machine.

C. Calibration Procedure

The change from electrical transducer strain gages operable at elevated temperatures to those operable at room temperatures facilitated calibration procedure and improved the accuracy with which calibrations could be performed. In elevated temperature calibrations, reach rod assemblies are used to transmit motion measured outside a heated enclosure to strain gages inside it. Consequently the lost motion and backlash in reach rod linkages was of concern in estimating calibration accuracy.

Room temperature calibration permits use of Tinius Olsen universal testing machine extensometer calibrating apparatus for strain gage calibrations. This apparatus is a heavy, vertical-acting micrometer which has provisions for reading length increments to the nearest 0.00001 inch. In use, the transducer core is mounted directly atop the micrometer spindle, and thus the transducer can be precisely displaced with respect to the transducer which is rigidly clamped in a stationary position. When calibrations are made, the full stroke of the transducer is measured. In the high range an 0.030-inch displacement is used, and in the low range an 0.003-inch displacement is used. Consequently the calibration accuracy range is two to three orders of magnitude greater than the measurement attempted.

The purpose of the calibration is the adjustment of compensating resistors within the read-out apparatus so that the micro-dial indicators precisely span the 1,000 unit range their resistance covers. In use these linear high precision potentiometers divide the total displacement voltage into 1,000 readable increments, each amounting to 0.00003- or 0.000003-inch, as the case may be.

Calibrations in effect require the balancing out of a complicated electrical network in which interaction occurs between individual segments. Consequently the calibration procedure is a matter of initially adjusting the individual network segments followed by readjusting to compensate for interactions introduced initially. Considerable trial and error is required to obtain electrical balances necessary for repeatability in all indicating circuits.

3 TEST AND CALIBRATION RESULTS

A. Tests

Approach

In the approach taken, it was first assumed that creep rates associate with the amount of plastic strain introduced into metals as a result of loading for creep testing. Thus to establish a base of departure, stress strain diagrams were developed from load-deformation diagrams resulting from tension tests. These stress-strain curves were drawn with attention to stresses associated with plastic strains in the 0.05 to 0.5 percent range.

Initial fifty-hour creep tests were made with materials loaded at stresses sufficient to produce strains indicated by tension tests. In applying these loads, steps to assure their application at strain-rates equivalent to those used in tension testing were taken. Results of these initial creep tests were used to determine stresses in which the onset of creep stresses may be expected in more precise testing.

In tests in which the onset of creep stresses are measured, procedures embodied in a specially constructed creep test machine are used to control creep test temperatures and the resolution of the creep strain measurements. In the onset of creep stress region the creep strains are quite small. For their measurement, the combination of very sensitive strain sensing devices and extended times allow cumulative creep to become appreciable, and resulting time deformation data are used to determine creep rates.

Materials

The three materials listed below were tested:

1. Ti-8Al-1Mo-1V, Duplex annealed.
2. Ti-6Al-4V, Mill annealed.
3. Ti-5Al-2 1/2 Sn, Mill annealed.

The materials listed were in the form of 0.050 by 36 by 96-inch sheet. All materials were procured on a commercial basis to obtain production rather than sample lot representations. Each material was supplied in the scale-free condition customary in the supply of commercial product. Any straightening or flattening represented by the sheets was that normal to commercial production. All materials were supplied with an annealed, de-scaled and flattened finish.

The chemical compositions of the materials are shown in Table 8. The mechanical properties of the materials in the various conditions reported by sources are listed in Table 9.

Materials Conditioning

The material conditioning steps required by various materials were accomplished in the General Dynamics/Convair Materials and Processes Laboratory by laboratory personnel. All furnaces were surveyed for temperature uniformity in the empty condition prior to use. Furnaces operating at less than 1000° F were within plus or minus 5° F, and those operating in the 1000 to 1850° F range were within plus or minus 15° F. Air atmospheres were used. In all cases the heat treat scale observed was light and mostly distinguished only by discoloration. In order to avoid difficulties from variations in scale removal processes, pickling or etching was not used to improve the appearance of the heat treated materials.

Heat Treatments

Ti-8Al-1Mo-1V. Some early tension and preliminary creep tests were made with material (TMCA Heat V-1555) which was supplied in the single annealed (1450° F, 8 hours, furnace cool) condition. Prior to the use this material was duplex annealed by treating it at 1450°F for 10 minutes and air cooling. The duplex annealed material (TMCA Heat D-4539) chiefly used for onset of creep stress testing was obtained from the mill in this condition.

Ti-6Al-4V. This material was tested in the "as received," mill-annealed condition.

Ti-5Al-2 1/2 Sn. This material was tested in the "as received," mill-annealed condition.

Test Procedure

Tension Tests. All tension tests were made in a 60,000 pound capacity Tinius Olsen Electromatic universal testing machine. This machine is provided with a Tinius Olsen electronic strain rate controller which can automatically control the strain rate within predetermined limits (ordinarily 0.003 to 0.007 inch per minute). Automatic strain rate control, however, was not used in these tests. Instead the unit was used as a strain pacer. By manually adjusting drive speeds with the infinitely variable Thymotrol speed control, tests were made at a strain rate of 0.0045 to 0.0055 inch per inch per minute. Calibrations with Morehouse proving rings showed the weighing accuracy of the machine to be better than plus or minus one-half of one percent.

All elevated temperature tension tests were heated in a 10-inch wide by 18-inch high by 24-inch deep, electrically heated, forced convection, box-type, testing machine furnace. Temperature control for this unit is effected by a thermocouple attached to the test specimen. This thermocouple actuates a strip-chart potentiometer-controller of 1/3 of 1 percent full scale accuracy which has its on-off control switches adjusted for plus or minus 2° F operation. The furnace is held to plus or minus 5° F temperature variation when surveyed in the empty condition. Tron-constantan thermocouples used with this unit are checked against Bureau of Standards secondary standard thermocouples in a Leeds and Northrup deep well furnace. Leeds and Northrup K-2 potentiometers are used throughout calibrations.

Strain pick up in tension testing utilizes modified Baldwin clamp-on reach rod assemblies which actuate Tinius Olsen Type S1, ASTM Type B, differential transformer extensometers. These extensometers have an accuracy of one part in ten thousand and are calibrated with a Tinius Olsen extensometer calibrating, super-micrometer device.

In the test performance, a tare load is applied to take up slack in gripping devices and proper seating of spherical grip mounts. Then the extensometer is attached and the test is carried out at the desired strain rate, whereupon the extensometer is removed and fracture is accomplished with a cross-head travel rate of 0.05-inch per minute.

Tension test specimen configuration is shown in Figure 109.

Creep Tests. Arcweld Model J and XJ 12,000-pound capacity creep test machines were used in preliminary creep testing. Calibration of these machines with Morehouse proving rings showed their accuracy to be one-half of one percent or better. Heat required for testing is supplied by Arcweld cylindrical vertical tube, electrically heated furnaces. Temperature surveys show these furnaces capable of maintaining temperatures within plus or minus 5° F. When furnaces are provided with supplementary external insulation and plugs in the top and bottom openings, temperature variations of plus or minus 2° F are obtainable. Temperature regulation during creep test is accomplished with chromel-alumel thermocouples attached to the centers of specimen gage lengths. These thermocouples actuate a 1/3 of 1 percent full scale accuracy potentiometer controller which governs the on-off input of furnace power. In addition to control thermocouples, recording thermocouples are attached at each end of the gage lengths of the specimens. The recording thermocouples serve to advise need for improved external insulation and plugging to optimize furnace temperature distribution.

Strain pick-up from creep specimens is done with Arcweld Model A-210 creep extensometers. These units are clamp-on reach rod devices which mechanically transfer strain indications to an externally positioned differential transformer extensometer. The extensometer output is amplified and modulated to provide input to a multi-point 1/3 of 1 percent full scale, strip-chart recorder which maintains a continuous record of the creep strains.

Loads are applied to the creep test machines by dead weights. In normal operation dead weight loading is accomplished by a weight elevator which permits a slow lowering of the weights for applying force to specimens. In these tests application of weights by the elevator was unsatisfactory. To overcome the elevators disadvantage, the dead weights were counterbalanced while they were supported by the elevator. To prevent impact loading, the counterbalanced dead weights were freed by lowering the elevator, and when freed, the counter weight was removed to gradually apply specimen loads.

The counter weight is a hopper bottomed bucket fitted with an adjustable hopper opening. In use this container is filled with a small lead shot, and these are slowly metered out to provide the desired slow rate of load application. Load application times range from four to seven minutes. Figure 109 shows the specimen configuration used for these tests.

Onset of Creep Stress Tests. Onset of creep stress test procedure is described on Pages 28 to 35 of this report.

Test Results

Tension test results with the three materials tested above are given in Tables 10, 11 and 12. Table 13 lists the 0.01 percent plastic strain stresses which were obtained when initial creep tests showed tendency for creep to appear at these stresses. Figures 110 to 112 and Tables 10 to 12 show data averages. Figures 113 to 115 show the modulii of elasticity used for stress strain diagram preparation.

Tables 14 to 28 summarize preliminary creep test results for Ti-8Al-1Mo-1V, Ti-6Al-4V, and Ti-5Al-2 1/2 Sn materials. Figures 116 to 130 and Tables 14 to 18 contain observed data and indicate the trends observed in these tests.

Tables 29 to 31 summarize results of onset of creep stress tests.

Discussion of Results

Tension Tests. Ti-8Al-1Mo-1V Duplex Annealed. The data shown in Table 10 and Figure 110 display stress-strain behoavior in the 450 to 600° F range. In this temperature range the stresses required to produce given amounts of strain decreased as temperatures increased without significantly altering the afine relationships of the stress strain curves. At 650° F, however, the stress-strain behavior changed and a tendency for the material to strain-harden early in straining was observed. This change occurred before yield strength offset, and suggested that the proportional limit of the material was changed as a result of strain hardening. Beyond yield strength offset, the stress-strain behavior at 600 and 650° F was practically identical.

Ti-6Al-4V Annealed. Table 11 and Figure 111 data show Ti-6Al-4V stress-strain behavior in the 450 to 650° F temperature range. The peculiarity of the 500, 550 and 600° F curves to "sag" at strains at and above yield strength strains is asserted, is of small magnitude, and apparently indicates data scatter rather than a significant physical event.

Ti-5Al-2 1/2 Sn Annealed. The data shown in Table 12 and Figure 112 display stress-strain behavior features of Ti-5Al-2 1/2 Sn. The tendency of this alloy to display stress-strain behavior akin to that exhibited by mild steel, especially at 450, 500 and 550° F is shown in the curves. This behavior is not surprising. It has been observed before in the inspection of titanium alloys at room temperature. The incidence of this behavior at 450° F and its disappearance at 600° F is of interest in the behavior of structural elements, but other than causing some possible distortion of proportional limit-temperature relationships would not seem to exert much effect on conditions associated with the onset of creep. The tendency for this alloy to strain harden rapidly at 650° F, like Ti-8Al-Mo-1V, also is shown by the curves.

Creep Tests

Introductory Comment. The creep tests discussed here were performed in conventional creep testing equipment with tension type specimens provided with 2-inch gage length sections. These tests were carried out in accordance with ASTM and ARTC practices in vogue. The strain measuring equipment used is equivalent to ASTM Type B extensometers. Strains were measured continuously throughout a 50 -hour test period, but for data recording purposes only selected points representative of the progress of primary and secondary creep were transferred to working charts. Secondary creep data given represent the solpe of a faired straight-line secondary creep curve which extends from the point of initiation of secondary creep to the 50-hour point. For convenience in calculating creep rates, the secondary creep curve is projected to the zero-time axis and curve slopes are taken over the full 50-hour period.

Throughout the creep testing discussed below, the appearance or non-appearance of creep was not orderly. In some cases creep would appear in one of a pair of duplicate tests and not in the mate. In other cases creep would disappear at one stress, to appear again at a lower stress. This was taken to indicate that the variations present in the materials themselves are great. Although variations in testing practice probably did influence test outcomes to a small degree, it is believed in view of precautions observed in testing, that material "scatter" exerts the predominant effect upon the data shown.

The erratic occurrence of significant data required performance of tests in greater numbers than originally expected. These occurrences also show that caution must be exercised in determining the stress at which creep disappearance may occur at various temperatures in various materials. In general enough tests should be made to provide sufficient data points to establish stress versus creep rate curves, and to assure that the lower stresses at which creep disappearances are observed are in fact those at which creep disappearance is present.

Ti-8Al-1Mo-1V Duplex Annealed. Stress versus creep rate data for Ti-8Al-1Mo-1V are listed in Tables 14 to 18 and plotted in Figures 116 to 120. Only those points at which creep occurred are plotted. Notations indicate those stresses at which non-occurence of creep was observed. Figure 117 shows results of creep tests at 450° F. Of six tests run, three resulted in data points insufficient to define a trend. The decrease in creep with decrease in stress was orderly. Figure 117 illustrates a case at 500° F where the disappearance of creep took place at one stress, only to appear at a lower stress. Figure 119, representative of conditions at 550° F, shows an orderly decrease of creep rate as stresses decrease. Figures 119 and 120 represent conditions at 600 and 650° F which are typical of the behavior of the material.

Tests with Ti-8Al-Mo-1V were made at stresses equivalent to those required to produce plastic strains from 0.05 to 0.25 percent in tension tests. These tests show tendency of the alloy to creep susceptibility in the presence of appreciable plastic strain resulting from load application.

Ti-6Al-4V Annealed. Stress versus creep rate data for Ti-6Al-4V listed in Tables 19 to 23 and charted in Figures 121 to 125 reiterate the conditions found in tests with Ti-8Al-1Mo-1V. In the case of the Ti-6Al-4V tests run at 500° F the appearance of creep arrest at a stress between those required to produce 0.01 and 0.05 percent plastic strain in tension tests was counter to the general observation that creep occurs in the presence of appreciable plastic strains.

Ti-5Al-2 1/2 Sn Annealed. Tables 24 to 28 list stress versus creep data, and Figures 126 to 130 chart this data for Ti-5Al-2 1/2 Sn. Because foregoing tests suggested that creep initiates in the presence of stresses required to produce strains of 0.01 percent or less in tension tests, and because of the peculiarities of the Ti-5Al-2 1/2 Sn stress strain curves the stresses used for creep testing Ti-5Al-2 1/2 Sn were found by ratioing the yield strength of the material. Usually the search started at 80 percent of the yield strength and proceeded by bracketing in 5 and then 2 1/2 percent increments. In the case of Ti-5Al-2 1/2 Sn this approach to an extent simplified the estimation of the creep arrest stress region. The method however was not productive of a greater number of data points for curve plotting since the material continued to creep or not creep at given stresses according to specimen idiosyncrasies. In general these tests shows that creep arrest could be expected at stresses slightly under the stress required to produce 0.01 percent strain in tension tests.

Onset of Creep Stress Tests

The test results obtained with Ti-8Al-1Mo-1V, Ti-6Al-4V and Ti-5Al-2 1/2 Sn at 450, 500, 550, 600 and 650° F are shown in Tables 29, 30 and 31 respectively. These data do not convincingly show that creep is halted by lowering the stresses into the ranges of values shown. To estimate the stresses at which creep action halts, it appears that further testing at stresses lower than those used will be necessary.

In the Ti-8Al-1Mo-1V tests at 600° F it appeared that the onset of creep stress of 67 KSI was found because at stresses under 67 KSI the non-appearance of creep was consistent, and at stresses above this, creep was observed. In the Ti-5Al-2 1/2 Sn tests at 500° F a similar event occurred, but the stress levels at which creep did or did not appear were too greatly separated to permit discrimination. Although the results obtained with Ti-5Al-2 1/2 Sn at 600° F suggested imminence of creep halt, the creep rates observed at higher stresses appeared too great to permit drawing conclusions. Apparently verification of the persistance of indicated non-creep conditions is required.

On the basis of the results shown, it is believed that the apparatus and methods described are suitable for determinations of onset of creep stresses. The test information indicated considerable variation in material behavior, and this may be attributable to the titanium alloys used. Follow-on tests with stainless steels are being made in a companion study. These will provide information useful for comparing titanium alloy with steel behavior in creep situations.

B. Calibrations

Temperature

The onset of creep test machine temperature calibrations were a series of trial runs in which a variety of control adjustments were made to obtain close regulation of specimen temperatures. Before beginning these runs, the steps described on Pages 37 and 38 were followed. In addition the thermocouples used throughout the trial runs were point checked prior to starting them. The object of these trial runs was to verify the ability of the heating system to maintain the accuracy indicated by 24-hour checks over prolonged periods of time.

The results of temperature surveys made during trial runs at 450, 500, 550, 600 and 650° F for times in the 150-hour to 200-hour range are shown in Tables 32 through 36. These data generally indicate that temperatures in the order of plus or minus 1° F are attainable. However the pronounced tendency shown in the data is for temperatures to fluctuate upward and downward in a 72 to 96-hour cycle. This is attributed to inadequate sensitivity in the control instruments. This can be improved by a factor of about 10 by providing thermocouple millivoltage bucking and operating the control instruments on the reduced differential millivoltage output. In short, this can reduce possible control instrument excursion from 8° F to 1° F in exercising the control function. This will not eliminate but will minimize the effect of the additive cyclic effects which arise from the parallel operation of the five heating zones comprising the heating unit.

The cyclic effects observed do not defeat the intent of tests, but they do require that the data be carefully scrutinized and related to deformation measurements preliminary to preparation of creep curves used for creep rate determinations. This results in the expenditure of considerable time in the reduction of raw data to form useful in-test outcome interpretation. Thus the moderate cost involved in control instrument up-grading can both reduce the cost of test performance and the time required to produce desired information.

Load System

Load system calibration data are shown in Table 37. These data were obtained from a series of loadings and unloadings of each load transmission system. With each incremental application or removal of dead weight, the tension produced in an electrical strain gage instrumented tension dynamometer was measured for inclusion in the data compiled in Table 37.

The data shown indicates that the load transmission systems do not operate in a linear manner and are subject to rotational effects arising out of lever arm and bell crank pivot movements. Although stress considerations governed the placement of lever arm pivots in the present instances, the calibrations indicate that the outcome is not desirable. In future lever arm manufacture the pivot working surfaces should be put in a single horizontal plane to eliminate effects inherent in their displacement from the single horizontal plane.

Table 1. Parts, Material, Stock & Heat Treat Lists — Creep Test Frame

Part Identity	Number Required	Stock Size	Material	Heat Treat	Reference
Bed Plate Assembly	1				Figure 3
Beam	4	12" x 72 lb Wide Flange	Structural Steel	None	
Reinforcing Plate	2	1 x 12 x 12	Structural Steel	None	
Reinforcing Plate	2	1 x 6 x 12	Structural Steel	None	
Stanchion Assembly	1			None	Figure 4
Backing Plate	1	1 x 25 x 48	Structural Steel	None	Figure 5
Top Plate	1	1/2 x 5 x 28	Structural Steel	None	Figure 5
Web Plate	10	1/2 x 5 / 11 3/4	Structural Steel	None	Figure 5
Locator Plate	1	1 x 3 1/2 x 28	Structural Steel	None	Figure 5
Load Support Column	1				
Vertical Thrust Beam	1				
Top Plate	1	1 x 5 7/8 x 30	Structural Steel	None	
Beam Block	1	4 x 14 x 30	Structural Steel	None	
Reinforcing Bar	1	1 1/2 x 1 1/2 x 30	Structural Steel	None	
Horizontal Thrust Beam	1				Figure 7
Front Face Plate	1	1 x 30 x 59 1/2	Structural Steel	None	Figure 7 & 8
Rear Face Plate	1	1 x 30 x 63 3/4	Structural Steel	None	Figure 7 & 8
Top Plate	1	1 x 9 7/8 x 30	Structural Steel	None	Figure 7
Bell Crank Support	1	4 x 7 x 30	Structural Steel	None	Figure 7 & 10
Stiffener	1	1/4 x 7 x 54	Structural Steel	None	Figure 7
Stiffener	2	1/4 x 7 x 14 7/8	Structural Steel	None	Figure 7
Beam Support Columns					Figure 12 & 13
Backing Webs	2	1/2 x 18 x 74 1/2	Structural Steel	None	Figure 12 & 13
Stiffening Flanges	4	1/2 x 8 1/2 x 74 1/2	Structural Steel	None	Figure 12 & 13
Attaching Flanges	2	1/2 x 15 1/2 x 84	Structural Steel	None	Figure 12 & 13
Foot Plates	2	1/2 x 12 x 18	Structural Steel	None	Figure 12 & 13
Shear Pads	2	1 x 7 x 7 3/4	Structural Steel	None	Figure 12 & 13
Assembly Hardware					
Key	1	1/2 x 1/2 x 30	SAE 1020 Steel	None	Figure 7 & 10
Dowel	6	1.375 Dia. x 3	SAE 1020 Steel	None	Figure 6 & 12
Bolt	12	3/4 - 16 NF x 2 3/4	SAE 1020 Steel*	None	Figure 6 & 12
Bolt	12	3/4 - 16 NF x 2 1/8	SAE 1020 Steel*	None	Figure 6 & 12
Nut	12	3/4 - 16 NF Hex.	SAE 1020 Steel*	None	Figure 6 & 12

*Or equivalent

Table 2. Load Transmission Assembly Arrangements

Item	Assembly 1	Assembly 2	Assembly 3	Assembly 4	Assembly 5	Assembly 6	Assembly 7	Assembly 8	Assembly 9
Weight Hanger Assy	40" Tie Rod	37" Tie Rod	40" Tie Rod	40" Tie Rod	37" Tie Rod	40" Tie Rod	40" Tie Rod	37" Tie Rod	40" Tie Rod
Lever Arm Assy	Long Arm Per Fig. 15	Short Arm Fulcrum Pivot Reversed	Long Arm Fulcrum Pivot Reversed	Long Arm Per Fig. 15	Short Arm Fulcrum Pivot Reversed	Long Arm Fulcrum Pivot Reversed	Long Arm Per Fig 15	Short Arm Fulcrum Pivot Reversed	Long Arm Fulcrum Pivot Reversed
Pull-Rod Assy	Short Turn-buckle Assy 27 Link Chain	Long Turn-buckle Assy 25 Link Chain	Short Turn-buckle Assy 27 Link Chain	Long Turn-buckle Assy 25 Link Chain	Short Turn-buckle Assy 27 Link Chain	Long Turn-buckle Assy 25 Link Chain	Short Turn-buckle Assy 27 Link Chain	Long Turn-buckle Assy 25 Link Chain	Short Turn-buckle Assy 27 Link Chain
Bell Crank Assy	Short Crank Long Hanger	Long Crank Short Hanger	Short Crank Long Hanger	Short Crank Long Hanger	Long Crank Short Hanger	Short Crank Long Hanger	Short Crank Long Hanger	Long Crank Short Hanger	Short Crank Long Hanger
Specimen Grip Assy	Long Bell Crank Clevis	Short Bell Crank Clevis	Long Bell Crank Clevis	Long Bell Crank Clevis	Short Bell Crank Clevis	Long Bell Crank Clevis	Long Bell Crank Clevis	Short Bell Crank Clevis	Long Bell Crank Clevis

Table 3. Parts, Material, Stock & Heat Treat Lists — Load Transmission Assembly

Part Identity	Number Required	Stock Size	Material	Heat Treat	Reference
Weight Hanger Assembly	9				Figure 14
Clevis Assembly	9				
Side Plates	18	3/4 x 2 x 3 9/16	SAE S-1 Tool Steel	320,000 Psi Uts	
Bottom Plates	9	1/2 x 1 1/2 x 1 9/16	SAE S-1 Tool Steel	320,000 Psi Uts	
Flat Heat Screws	36	10 - 32 NF	SAE 4130	180,000 Psi Uts	
Tie Rod	6	1/2 Dia x 40	SAE 1020 Steel	None	
Tie Rod	3	1/2 Dia x 37	SAE 1020 Steel	None	
Weight Support Plate	9	1/2 x 2 x 4	Structural Steel	None	
Lever Arm Assembly	9				Figure 15
Lever Arm	6	1 1/4 x 4 1/2 x 19	SAE 4130	Normalize	Figure 16 & 17
Lever Arm	3	1 1/4 x 4 1/2 x 34	SAE 4130	Normalize	
Weight Hanger Knife Edge Pivot	9	3/4 x 3/4 x 2 15/16	SAE S-1 Tool Steel	320,000 Psi Uts	Figure 18
Lever Fulcrum Knife Edge Pivot	9	1 x 1 9/16 x 3	SAE S-1 Tool Steel	320,000 Psi Uts	Figure 19
Pull Rod Knife Edge Pivot	9	1 x 2 3/8 x 3	SAE S-1 Tool Steel	320,000 Psi Uts	Figure 20
Socket Head Cap Screw	18	5/16 - 24 x 1 1/4	Commercial Item	None	
Recessed Socket Headless Cap Screw	18	5/8 - 18 x 1	Commercial Item	180,000 Psi Uts	
Recessed Socket Headless Cap Screw	18	1/2 - 20 x 1	Commercial Item	70,000 Psi Uts	
Pull Rod Assembly					
Pull Rod Attachment Link	9	1 7/8 x 3 x 6 1/2			Figure 21
Roller Chain (Rex Type 140)	5	27 Links (47 1/4)	Commercial Item	None	
Roller Chain (Rex Type 140)	4	25 Links (43 3/4)	Republic Supply Co., Los Angeles		
Turnbuckle Assembly	9				Figure 22
Barrel	9	1 1/2 x 4 Hexagon	SAE 4130 Steel	160,000 Psi Uts	Figure 23
Chain Clevis Assembly				160,000 Psi Uts	Figure 24
Side Bars	18	3/8 x 2 1/4 x 4	SAE 4130 Steel	Normalized	Figure 25
Yoke	9	1 x 1 1/2 x 2 1/4	SAE 4130 Steel	Normalized	Figure 25
Shank	9	1 Dia x 5 1/2	SAE 4130 Steel	Normalized	Figure 25
Bell Crank Clevis Assy	9			160,000 Psi Uts	Figure 26
Side Bars	18	3/8 x 2 1/2 x 4	SAE 4130 Steel	Normalized	Figure 27
Yoke	9	1 x 1 1/2 x 2 1/4	SAE 4130 Steel	Normalized	Figure 27
Shank	9	1 Dia x 4 1/2	SAE 4130 Steel	Normalized	Figure 27
Pin	9	1/2 Dia x 2 15/16	SAE 4130 Steel	Normalized	
Pin	9	1/2 Dia x 1 7/8	SAE 4130 Steel	Normalized	
Bell Crank Assembly	9				Figure 28
1 To 1 Bell Crank	6	7/8 x 5 1/2 x 7	SAE 1020 Steel	None	
2 To 1 Bell Crank	3	7/8 x 5 1/2 x 10	SAE 1020 Steel	None	
Needle Bearing	27	9N3K1427YZP	Torrington	None	
Specimen Grip Assembly - Bell Crank Attachment	9				Figure 29
Bell Crank Connector	3	2 1/2 Dia x 5 1/2	SAE 4130 Steel	Normalize	Figure 30
Bell Crank Connector	6	2 1/2 Dia x 8 1/2	SAE 4130 Steel	Normalize	Figure 30
Lock Nut	9	2 1/2 Dia x 3/8	SAE 1020 Steel	None	Figure 30
Coupling Stud	9	1 1/4 Dia x 5 3/4	SAE 4130 Steel	Normalize	Figure 30
Universal Joint	18	Type J	Boston Gear Co.	None	
Specimen Grip Assembly	18				
Body	18	2 1/2 Dia x 11	SAE 4130 Steel	Normalize	Figure 31
Plate	18	3/8 x 1 1/2 x 7	SAE 4130 Steel	Normalize	
Bolt	18	ANC-6-11			
Bolt	18	ANC-8-11			
Specimen Grip Assembly - Stanchion Attachment	9				Figure 29
Tension Rod Connector	9				Figure 32
Connector Nut	9				Figure 32
Nut Bearing Plate	9				Figure 32
Universal Joint	See Above				
Specimen Grip Assembly	See Above				

Table 3. Parts, Material, Stock & Heat Treat Lists — Load Transmission Assembly (Continued)

Part Identity	Number Required	Stock Size	Material	Heat Treat	Reference
Lever Arm Support					Figure 33
Bearing Pad	18	3/4 x 3/4 x 1	SAE S-1 Tool Steel	320,000 Psi Uts	Figure 34
Bearing Pad Support	9	3 x 3 1/4 x 3 1/2	SAE 1020 Steel	None	
Dowels	27	1/4 Dia x 1 Long	SAE 1020 Steel	None	
Machine Bolts	27	3/8 - 24 NF x 1 1/4 Long - 3/4 Min	SAE 1020 Steel or Equivalent	None	
Bell Crank Support				160,000 Psi Uts	Figure 36
Top Plate	9	1/2 x 2 3/4 x 6	SAE 4130 Steel	Normalized	
End Plate	9	3/4 x 2 3/4 x 4 1/4	SAE 4130 Steel	Normalized	
Mounting Bar	9	1 1/4 x 2 [illegible] 2 3/4	SAE 4130 Steel	Normalized	
Rib Plates	12	3/8 x 4 1/4 x 8	SAE 4130 Steel	Normalized	
Rib Plates	6	3/8 x 4 1/4 x 7	SAE 4130 Steel	Normalized	
Pivot Bolt Assembly					Figure 37
Bolt	27	7/8 Hex x 2 9/16	SAE 4130 Steel	160,000 Psi Uts	
Spacer	54	1 1/4 Dia x 1/8	SAE 1020 Steel	None	
Spacer	27	9 1/4 Dia x 5/32	SAE 1020 Steel	None	
Nut	27	9/16 - 18 NF Castellated Hex.	SAE 1020 Steel or Equivalent	None	

Table 4. Heating Unit Core Parts, Material & Stock Lists

Part Identity	Item Number	Number Required	Material	Stock Size	Reference
Top-Bottom Lay-up					
Plates	9, 11, 16, 18	4	Monel Metal	1 x 30 x 96	Figure 43 & 45
Separators	10, 17	2	Asbestos Millboard	1/16 x 30 x 96	Figure 44
Spacers	12-13	2	Monel Metal	1 1/2 x 2 x 96	Figure 46
	14-15	8	Monel Metal	1 x 1 1/2 x 96	Figure 46
Side Lay-up					
Plates	23, 25, 30, 32	4	Monel Metal	1 x 5 1/2 x 96	Figure 50
Separators	24, 31	2	Asbestos Millboard	1 1/6 x 5 1/2 x 96	Figure 48
Heat Distributor					
Top-Bottom Sheets	7, 20	2	O.F.H.C. Copper	.2052 x 36 x 96 1/2	Figure 52
Side Sheets	27, 34	2	O.F.H.C. Copper	.2052 x 5 5/8 x 96 1/2	Figure 54
End Sheets	38, 42	2	O.F.H.C. Copper	.2052 x 5 5/8 x 34 3/8	Figure 56
Top-Bottom Separator	8, 19	2	Asbestos Millboard	1/8 x 36 x 96 1/2	Figure 53
Side Separators	26, 33	2	Asbestos Millboard	1/8 x 36 x 96 1/2	Figure 55
End Separators	37, 41	2	Asbestos Millboard	1/8 x 5 5/8 x 96 1/2	Figure 57
Hardware					
Locking Pin	-	26	Type 302 Stainless Steel	3/8 Dia x 3 1/2	-
Locking Pin	-	4	Type 302 Stainless Steel	3/8 Dia x 5 1/2	-
Hex Head Cap Screw	-	16	Type 302 Stainless Steel	3/8 - 16UNC x 3	-
Hex Head Cap Screw	-	288	Type 302 Stainless Steel	1/4 20UNC x 1 1/4	-
Heater Clamps					
Top-Bottom	5, 22	32	Type 302 Stainless Steel	3/8 x 2 x 34 3/4	Figure 51
Side	29, 36	4	Type 302 Stainless Steel	3/8 x 2 x 96	Figure 51
End	40, 44	4	Type 302 Stainless Steel	3/8 x 2 x 34 1/4	Figure 51

Table 5. Heating Unit Insulation Parts, Material & Stock Lists

Part Identity	Item Number	Number Required	Material	Stock Size	Reference
Heating Platten Core Insulation					Figure 58 & 59
Bottom	2, 3	2	Marinite	2 x 47 x 116	Figure 60
Bottom	4	1	Marinite	2 x 39 x 116	Figure 61
Side	45, 46	2	Marinite	2 x 11 1/8 x 112	Figure 62
Enclosure Corner Blocks	54, 55, 56, 57	4	Marinite	2 x 5 5/8 x 10	Figure 63
Enclosure Retaining Blocks	50, 51, 52, 53	4	Marinite	2 x 3 x 11 1/8	Figure 64
Batting	None	6	Spintex	2 x 30 x 48	
Top Assembly	58	1			Figure 65
Panel		1	Marinite	2 x 39 x 96	Figure 65
Spacer		2	Marinite	2 x 1 1/2 x 39	Figure 66
Spacer		4	Marinite	2 x 1 1/2 x 28	Figure 65
End (Facing Load Support Column)					
Enclosure	49	1	Marinite	2 x 5 1/2 x 39	Figure 67
Filler	48	1	Marinite	2 x 5 1/2 x 43	Figure 68
End (Facing Stanchion)					
Enclosure	49	1	Marinite	2 x 5 1/2 x 39	Figure 69
Enclosure, Removable	64	1	Marinite	2 x 3 1/2 x 39	Figure 70
Filler	47	1	Marinite	2 x 5 1/2 x 43	Figure 71
Filler, Removable	63	1	Marinite	2 x 3 1/2 x 39	Figure 70
Access Cover					
Top	67, 76	2	Marinite	2 x 8 x 39	Figure 77
Top Filler	66, 75	2	Marinite	2 x 10 x 47	Figure 72
Corner	69, 70, 78, 79	4	Marinite	2 x 5 1/2 x 10	Figure 73
Side	72, 73, 81, 82	4	Marinite	2 x 5 1/2 x 8	Figure 74
End Enclosure	71, 80	2	Marinite	2 x 5 5/8 x 39	Figure 76
End Filler	68, 77	2	Marinite	2 x 5 5/8 x 43	Figure 75
Enclosure Box Assembly	-	1			Figure 79
Side Pieces	-	2	6061-T6 Alum.	.060 x 17 1/8 x 116	
Side Piece Flanges	-	2	6061-T6 Alum.	3/16 x 1 1/2 x 1 1/2 x 96 Angle	
Side Piece Flanges	-	4	6061-T6 Alum.	3/16 x 1 1/2 x 1 1/2 x 9 1/8 Angle	
Side Piece Flanges	-	4	6061-T6 Alum.	3/16 x 1 1/2 x 1 1/2 x 11 1/2 Angle	
Bottom Piece	-	1	6061-T6 Alum.	.060 x 47 x 116	
End Pieces	-	2	6061-T6 Alum.	.060 x 9 1/2 x 47	
End Piece Flanges	-	4	6061-T6 Alum.	3/16 x 1 1/2 x 1 1/2 x 8	
End Piece Flanges	-	2	6061-T6 Alum.	3/16 x 1 1/2 x 1 1/2 x 5	
End Piece Flanges	-	2	6061-T6 Alum.	3/16 x 1 1/2 x 1 1/2 x 39	
Access Covers		2			
Top Piece		2	6061-T6 Alum.	.060 x 10 x 47	
Side Pieces		4	6061-T6 Alum.	.060 x 7 5/8 x 10	
End Pieces	-	2	6061-T6 Alum.	.060 x 7 5/8 x 47	
Top Flanges		2	6061-T6 Alum.	3/16 x 1 1/2 x 1 1/2 x 50 Angle	
End Flanges		4	6061-T6 Alum.	3/16 x 1 1/2 x 1 1/2 x 10 5/8 Angle	
Bottom Flanges		4	6061-T6 Alum.	3/16 x 1 1/2 x 1 1/2 x 11 1/2 Angle	
End Flanges		4	6061-T6 Alum.	3/16 x 1 1/2 x 1 1/2 x 9 1/2 Angle	
End Flanges		2	6061-T6 Alum.	3/16 x 1 1/2 x 1 1/2 x 9 1/2 Angle	
Retainer Angle		2	6061-T6 Alum.	1/8 x 2 1/2 x 3 1/2 x 3 Angle	
Retainer		8	6061-T6 Alum.	1/8 x 2 x 43	
Machine Screw & Nut		54	Steel	3/16 x 5	
Access Cover Insert		1			
End Piece		2	6061-T6 Alum.	.060 x 3 1/2 x 39	
Top & Bottom Flanges		4	6061-T6 Alum.	3/16 x 1 1/2 x 1 1/2 x 39 Angle	
Side Flanges		4	6061-T6 Alum.	3/16 x 1 1/2 x 1 1/2 x 5 Angle	
Enclosure Top		1			
Top Sheet		2	6061-T6 Alum.	.060 x 25 x 96	
End Flanges		2	6061-T6 Alum.	3/16 x 1 1/2 x 1 1/2 x 47 Angle	
Side Flanges		2	6061-T6 Alum.	3/16 x 1 1/2 x 1 1/2 x 96 Angle	
Hardware					
Welding Rod		10 lbs	4043 Alum.	3/16 Dia	
Machine Screw & Nut		36	Steel	3/16 Dia x 5	

Table 6. Power Supply Electrical Equipment List

Name	Number of Item	Designation	Description
Safety Switch	1	Square D, Cat.No. A86342	3-Pole, 480 Volt, 60 Ampere
Transformer	1	General Electric Cat.No. 9T21A9103	15 KVA, Dry Type, Single Phase, 60 Cycle
Circuit Breaker Center			
Basic Device	1	Square D No. Q012	Single Phase, 12 Pole, Gen'l Purpose
Basic Device Cover	1	Square D No. Q012S	
Circuit Breaker	5	Square D No. Q0200	120/240 Volt, Plug-in Type
Relay Center			
Relay	5	Allen Bradley Bulletin 700, Cat.No. 700D20	2 Pole, Normally Open, 25 amp, 300 volt, 120 Volt, 60 Cycle Coils
Enclosure		Square D	4" x 10" x 10" Hinged Cover Cutout Box
Heater	44	Watlow CA940X	330 Watt, 240 Volt, 1" Wide x 35 7/16" Long
Wiring Detail			
Grounding Strip	100 ft	Perforated Copper (Commercial)	
Cutout Box	2	Square D Cat. LD42	
Flexible Metallic Conduit	30 ft	1 1/4 Dia (Commercial)	
Flexible Metallic Conduit Connector	2	No. 308	
Flexible Metallic Conduit 90 Deg. Connector	2	No. 327	
Flexible Metallic Conduit	40 ft.		
Flexible Metallic Conduit Connector	5	No. 306	
Flexible Metallic Conduit 90° Connector	5	No. 326	

Table 7. Strain-Gage Attachment Parts, Material & Stock Lists

Part Identity	Number Required	Material	Stock Size	Reference
Transducer Holder Fixture	18			
Transducer Holder	18	Type 303 St. St	5/8 x 1 1/4 x 2 7/8	Figure 89
Transducer Holder Clamp	18	Type 303 St. St	1/4 x 1 1/4 x 1 7/8	Figure 90
Roller	36	Type 303 St. St	5/16 Dia x 7/16	Figure 95
Pin	36	Drill Rod	1/16 Dia x 1	Figure 100
Adjustment Fixture	18			
Body	18	Type 303 St. St	1/4 x 1 x 2 3/4	Figure 91
Clamp	18	Type 303 St. St	1/4 x 1 x 2 3/4	Figure 92
Screw Holder	18	Type 303 St. St	1/4 x 3/4 x 1	Figure 93
Push Rod Guide	18	Type 303 St. St	3/8 x 3/8 x 1	Figure 94
Roller	36	Type 303 St. St	5/16 Dia x 7/16	Figure 95
Pin	36	Drill Rod	1/16 Dia x 1	Figure 100
Push Rod Assembly				
Rod	18	Type 303 St. St	1/8 Dia x 17 9/16	Figure 101
Coupling	18	Type 303 St. St	1/4 Dia x 15/16	Figure 97
Support	36	Type 303 St. St	1/4 x 1 x 1	Figure 96
Roller	36	Type 303 St. St	5/16 Dia x 1/2	Figure 98
Pin	36	Drill Rod	1/16 Dia x 1	Figure 100
Hardware				
Spring	18	No. C-151B		California Spring Co.
Screw	144	Steel	6 - 32 x 5/8	
Screw	144	Steel	6 - 32 x 7/8	
Screw	144	Steel	0 - 80 x 1/4	
Screw	36	Steel	6 - 40 x 2	

Table 8. Chemical Analysis of Materials

Element	Material		
	Ti-8Al-1Mo-1V	Ti-6Al-4V	Ti-5Al-2 1/2 Sn
Carbon	0.022%	0.023%	0.025%
Molybdenum	1.10%	—	—
Vanadium	1.00%	4.10%	—
Aluminum	7.60%	5.90%	5.20%
Tin	—	—	2.30%
Nitrogen	0.012%	0.016%	0.015%
Hydrogen	0.014%	0.006%	0.006%
Oxygen	0.085%	—	—
Iron	0.08%	0.12%	0.33%

Table 9. Mechanical Properties of Materials

Material	Heat No.	Condition	Mechanical Properties		
			Yield Strength KSI	Ultimate Strength KSI	Elongation %
Ti-8Al-1Mo-1V	V-1555 (a)	Single Annealed	148.5	153.4	11.5
		Duplex Annealed	138.5	149.2	10.0
	D-4539 (a)	Duplex Annealed	134.5	149.9	14.0
Ti-6Al-4V	D-4321 (a)	Mill Annealed	134.0	139.0	13.0
Ti-5Al-2 1/2 Sn	D-2242 (a)	Mill Annealed	127.5	132.1	16.3

(a) Titanium Metal Corporation of America

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Table 10. Mechanical Proper

Temp °F	Offset-I				
	0.05	0.10	0.15	0.20	0.25
	Stress				
450	85.6	89.5	92.2	93.6	94.3
	87.3	90.7	92.7	93.8	94.6
	82.0	88.4	91.8	92.6	93.3
	Ave. 84.9	89.6	92.2	93.3	94.1
500	79.6	85.9	88.9	90.7	91.7
	83.1	86.8	89.4	90.6	91.8
	83.9	87.8	90.3	91.6	92.2
	Ave. 82.2	86.8	89.5	91.0	91.9
550	83.6	84.3	86.2	87.9	88.9
	76.9	81.4	84.6	86.3	87.6
	82.0	86.0	87.3	88.1	88.6
	Ave. 80.8	83.9	86.0	87.4	88.3
600	76.9	81.3	84.2	85.9	86.5
	69.8	76.4	79.3	82.1	84.0
	75.9	79.7	82.4	84.4	85.4
	Ave. 74.2	79.2	82.0	84.1	85.3
650	76.0	80.7	82.8	84.5	85.1
	76.0	79.8	81.9	83.6	84.4
	76.6	81.1	83.4	84.7	85.3
	Ave. 76.2	80.6	82.7	84.3	84.9

*Heat No. 0.050" x 36" x 96" Sheet; Double Annealed.

F 2

ties of Ti-8Al-1Mo-IV* at 450 to 650° F

ercent					Ultimate Strength KSI	Elongation % in 2"
0.30	0.35	0.40	0.45	0.50		
-KSI						
94.9	95.3	95.5	95.7	95.9	113.0	12.0
95.2	95.6	95.9	96.3	96.5	112.0	11.0
93.8	94.1	94.5	95.0	95.2	111.1	11.5
94.6	95.0	95.3	95.7	96.2	112.0	11.5
92.1	92.4	92.8	93.1	93.1	109.5	11.0
92.2	92.5	92.7	93.0	93.0	110.0	10.5
92.4	92.6	93.2	93.4	93.4	109.5	11.5
92.2	92.5	92.9	93.2	93.2	109.7	11.0
89.3	89.7	89.8	90.4	90.6	108.4	11.0
88.2	88.4	89.0	89.3	89.5	106.7	12.0
89.0	89.4	89.8	90.2	90.5	106.7	11.0
88.8	89.1	89.2	90.0	90.2	107.3	11.3
87.1	87.2	87.6	88.0	88.4	104.2	11.0
85.4	86.1	86.8	87.0	87.3	104.7	12.0
85.9	86.3	86.7	87.3	87.7	103.9	11.0
86.1	86.6	87.7	87.5	87.8	104.3	11.3
86.0	86.5	86.8	87.4	88.0	102.9	11.0
85.5	85.9	86.3	86.9	87.6	102.4	11.0
86.2	86.4	86.8	87.4	87.8	102.4	11.0
85.9	86.3	86.8	87.2	87.8	102.6	11.0

B1

Table 11. Mechanical Properties of

Temp °F		Offset-Percent					
		0.05	0.10	0.15	0.20	0.25	0.30
		Stress-KSI					
450		100.2	100.3	99.7	99.6	100.1	99.7
		95.2	99.5	100.7	101.5	101.3	101.2
		104.5	106.9	107.3	106.4	105.8	105.6
	Ave.	100.0	102.2	102.6	102.5	102.4	102.2
500		95.2	96.5	96.6	96.5	96.6	96.9
		93.5	95.0	95.0	95.0	95.2	95.5
		94.0	94.8	94.5	94.9	95.1	95.2
	Ave.	94.2	95.4	95.4	95.5	95.6	95.9
550		86.6	89.5	90.7	91.4	91.6	92.0
		91.6	92.6	92.7	92.8	93.5	93.8
		88.0	91.4	92.3	92.7	92.8	93.1
	Ave.	88.7	91.2	91.9	92.3	92.6	93.0
600		88.7	90.3	90.4	91.5	91.5	91.7
		89.8	90.4	90.7	91.0	91.5	92.1
		83.5	87.9	89.9	89.9	90.6	91.0
	Ave.	87.3	89.5	90.3	90.8	91.2	91.6
650		73.8	82.3	85.1	86.8	88.0	88.5
		80.5	86.6	89.4	90.6	90.8	91.7
		88.0	88.1	88.6	89.0	89.1	89.7
	Ave.	80.8	85.7	87.7	88.8	89.3	90.0

B 2

Ti-6Al-4V at 450 to 650° F

	0.35	0.40	0.45	0.50	Ultimate Strength KSI	Elongation % in 2"
	99.9	100.0	100.2	104.3	121.7	11.0
	101.6	101.7	101.7	101.7	117.9	11.0
	106.0	106.0	106.0	106.2	120.4	10.0
	102.5	102.6	102.6	104.1	120.0	10.7
	97.2	97.4	97.8	98.0	111.7	9.5
	95.8	96.0	96.2	96.2	109.3	10.0
	95.5	95.7	96.1	96.5	112.2	9.5
	96.2	96.4	96.7	96.9	111.1	9.7
	92.4	92.8	93.1	93.5	107.8	8.5
	94.3	94.6	94.9	95.3	110.3	9.5
	93.5	94.1	94.3	94.7	111.6	8.8
	93.4	93.8	94.1	94.5	109.9	8.9
	91.8	92.5	93.1	93.5	105.7	8.3
	92.7	93.1	93.6	93.9	105.9	8.8
	91.6	92.0	92.6	93.4	106.5	9.0
	92.0	92.5	93.1	93.6	106.0	8.7
	88.9	89.3	89.7	90.2	103.1	8.5
	92.3	92.8	93.2	93.4	105.0	9.0
	90.2	90.8	91.0	91.4	103.5	8.0
	90.5	91.0	91.3	91.7	103.9	8.5

Table 12. Mechanical Proper

Temp °F	Offset-I				
	.05	0.10	0.15	0.20	0.25
	Stress				
450	88.3	84.6	84.0	83.0	81.8
	81.5	80.6	79.6	78.5	77.2
	84.0	82.9	81.6	80.1	79.2
	Ave. 82.9	82.7	81.7	81.4	79.4
500	78.8	78.8	78.3	78.0	77.7
	80.8	80.4	79.5	78.9	77.9
	78.5	78.5	78.4	78.2	78.0
	Ave. 79.4	79.2	78.7	78.4	77.9
550	74.8	74.9	74.4	74.1	73.8
	74.7	75.7	75.8	75.8	75.4
	69.8	70.4	70.4	69.9	69.3
	Ave. 73.1	73.7	73.5	73.3	72.8
600	70.0	70.2	69.8	69.3	68.8
	70.1	70.1	69.7	69.5	69.3
	65.2	67.7	68.2	68.6	68.6
	Ave. 68.4	69.3	69.2	69.1	68.6
650	67.3	68.2	68.6	68.6	68.4
	68.4	69.7	69.7	69.5	69.0
	71.6	72.2	71.8	71.3	70.9
	Ave. 69.1	70.0	70.0	69.8	69.4

2

ties of Ti-5Al-2 1/2 Sn at 450 to 650° F

ercent					Ultimate Strength KSI	Elongation % in 2"
0.30	0.35	0.40	0.45	0.50		
-KSI						
80.8	80.1	79.3	79.3	79.3	95.3	19.0
75.6	75.0	75.5	75.5	75.6	94.8	21.0
78.9	79.1	79.2	79.2	79.3	93.9	18.0
78.4	78.1	78.0	78.0	78.1	94.7	19.3
77.2	76.7	76.0	75.3	75.9	94.0	18.0
77.5	77.1	76.9	76.8	76.8	93.2	18.0
77.8	77.5	77.3	76.6	76.4	95.2	17.5
77.5	77.1	76.7	76.2	76.4	94.1	17.8
73.6	73.5	73.4	73.4	73.4	91.0	19.0
75.0	74.7	74.4	74.3	74.1	94.2	19.5
69.1	68.9	68.7	68.5	68.5	89.0	20.0
72.6	72.4	72.2	72.1	72.0	91.4	19.5
68.3	67.9	67.8	67.7	67.4	86.4	18.0
69.1	69.1	69.1	69.1	69.0	87.7	17.5
68.3	68.1	67.8	67.7	67.6	84.9	20.0
68.6	68.4	68.2	68.2	68.0	86.3	18.5
68.4	68.3	68.3	68.3	68.4	86.2	16.5
68.9	68.9	68.9	69.1	69.2	86.9	16.5
70.9	70.9	70.9	70.9	71.1	88.0	16.5
69.4	69.4	69.4	69.4	69.6	87.0	16.5

Table 13. Average Stresses Required for 0.01 Percent Tensile Strain

Material	Temperature - °F				
	450	500	550	600	650
	Stress-KSI				
Ti-8Al-1Mo-1V D.A.	75.5	74.1	71.8	62.9	67.9
Ti 6Al-4V Ann	85.6	84.1	68.9	70.5	66.8
Ti 5Al-2 1/2 Sn Ann	80.8	74.0	64.9	66.0	64.2

Table 14. Summary of Creep Test Results
Ti-8Al-1Mo-1V
450° F

Specimen No.	Stress KSI	Secondary Creep Rate In/In/Hr
1	92.3	0.0000086
2	92.3	0.0000070
3	85.0	0.0000028
4	85.0	Nil
5	71.5	Nil
6	71.5	Nil

Table 15. Summary of Creep Tests Results
Ti-8Al-1Mo-1V
500° F

Specimen No.	Stress KSI	Secondary Creep Rate In/In/Hr
1	91.9	0.000020
2	91.9	0.000023
3	91.1	0.000004
4	91.1	0.000004
5	82.2	0.000004
6	82.2	0.000004
7	71.6	0.000006
8	71.6	0.000008

Table 16. Summary of Creep Test Results
Ti-8Al-1Mo-1V
550° F

Specimen No.	Stress KSI	Secondary Creep Rate In/In/Hr
1	87.5	0.000009
2	87.5	0.000007
3	86.0	0.000012
4	86.0	0.000025
5	83.9	0.000025
6	83.9	0.000012
7	80.8	0.000003
8	80.8	Nil

Table 17. Summary of Creep Test Results
Ti-8Al-1Mo-1V
600° F

Specimen No.	Stress KSI	Secondary Creep Rate In/In/Hr
1	86.1	0.000026
2	86.1	0.000018
3	84.1	Nil
4	84.1	0.000007
5	79.2	0.000004
6	79.2	Nil
7	74.2	Nil
8	74.2	Nil

Table 18. Summary of Creep Test Results
Ti-8Al-1Mo-1V
650° F

Specimen No.	Stress KSI	Secondary Creep Rate In/In/Hr
1	84.2	0.000040
2	84.2	0.000096
3	83.3	0.000072
4	83.3	0.000076
5	80.5	0.000064
6	80.5	0.000044
7	76.2	Nil
8	76.2	Nil

Table 19. Summary of Creep Test Results
Ti-6Al-4V
450° F

Specimen No.	Stress KSI	Secondary Creep Rate In/In/Hr
1	100.0	0.000009
2	100.0	0.000012
3	97.2	0.000001
4	97.2	Nil
5	94.8	Nil
6	94.8	Nil
7	94.5	0.000002
8	94.5	
9	93.3	0.000012
10	93.3	0.000006

Table 20. Summary of Creep Test Results
Ti-6Al-4V
500° F

Specimen No.	Stress KSI	Secondary Creep Rate In/In/Hr
1	95.5	0.000008
2	95.5	Nil
3	94.2	0.000092
4	94.2	0.000008
5	90.6	Nil
6	90.6	Nil
7	88.4	Nil
8	88.4	Nil
9	88.4	Nil
10	88.4	Nil

Table 21. Summary of Creep Test Results
Ti-6Al-4V
550° F

Specimen No.	Stress KSI	Secondary Creep Rate In/In/Hr
1	92.3	0.000018
2	92.3	Nil
3	88.7	0.000006
4	88.7	Nil
5	85.4	0.000006
6	85.4	0.000001
7	82.9	0.000002
8	82.9	0.000009
9	80.6	Nil
10	80.6	0.000013

Table 22. Summary of Creep Test Results
Ti-6Al-4V
600° F

Specimen No.	Stress KSI	Secondary Creep Rate In/In/Hr
1	90.8	0.000066
2	90.8	0.000016
3	87.3	0.000023
4	87.3	0.000024
5	84.0	Nil
6	84.0	0.000032
7	81.8	Nil
8	81.8	Nil
9	79.5	0.000013
10	79.5	0.000012

Table 23. Summary of Creep Test Results
Ti-6Al-4V
650° F

Specimen No.	Stress KSI	Secondary Creep Rate In/In/Hr
1	88.8	0.000040
2	88.8	0.000030
3	80.8	0.000022
4	80.8	Nil
5	76.3	0.000009
6	76.3	Nil
7	73.9	0.000023
8	73.9	Nil
9	69.4	0.000019
10	69.4	Nil

Table 24. Summary of Creep Test Results
Ti-5Al-2 1/2 SN
450° F

Specimen No.	Stress KSI	Secondary Creep Rate In/In/Hr
1	82.9	0.000018
2	82.9	—
3	78.0	0.000010
4	78.0	0.000010
5	73.2	0.000072
6	73.2	0.000016
7	69.2	Nil
8	69.2	0.000012
9	67.0	Nil
10	67.0	Nil

Table 25. Summary of Creep Test Results
Ti-5Al-2 1/2 SN
500° F

Specimen No.	Stress KSI	Secondary Creep Rate In/In/Hr
1	78.5	0.000020
2	78.5	0.000025
3	77.3	0.000002
4	77.3	0.000010
5	70.6	0.000004
6	70.6	Nil
7	68.5	0.000010
8	68.5	Nil
9	66.5	Nil
10	66.5	Nil

Table 26. Summary of Creep Test Results
Ti-5Al-2 1/2 SN
550° F

Specimen No.	Stress KSI	Secondary Creep Rate In/In/Hr
1	73.1	0.000015
2	73.1	0.000015
3	72.0	0.000011
4	72.0	0.000005
5	65.9	Nil
6	65.9	Nil

Table 27. Summary of Creep Test Results
Ti-5Al-2 1/2 SN
600° F

Specimen No.	Stress KSI	Secondary Creep Rate In/In/Hr
1	68.4	0.000015
2	68.4	0.000015
3	66.3	0.000002
4	66.3	0.000004
5	64.0	Nil
6	64.0	Nil

Table 28. Summary of Creep Test Results
Ti-5Al-2 1/2 SN
650° F

Specimen No.	Stress KSI	Secondary Creep Rate In/In/Hr
1	69.1	0.000008
2	69.1	Nil
3	66.3	0.000009
4	66.3	0.000012
5	64.6	Nil
6	64.6	0.000026
7	62.9	Nil
8	62.9	Nil

Table 29. Onset of Creep Stress Measurements of Ti-8Al-1Mo-1V

Temperature °F	Stress KSI	Creep Rate In./In./Hr.
450	65.2	.000000010
450	66.7	.000000010
450	66.8	.000000010
450	67.8	NIL
450	78.8	.000000022
450	79.3	.000000050
500	60.7	.000000040
500	62.2	.000000060
500	63.2	.000000011
500	63.2	.000000015
500	71 .8	.000000100
500	72.3	NIL
550	59.0	.000000049
550	60.5	.000000011
550	69.4	.000000005
550	69.4	Mal-Function
550	68.7	.000000060
550	70.5	NIL
600	65.0	NIL
600	66.8	NIL
600	66.8	NIL
600	67.3	.000000012
600	67.3	.000000024
600	69.0	NIL
650	47.8	.000000625
650	49.3	.000000067
650	51.8	NIL
650	52.6	.000000010
650	55.3	NIL
650	55.6	.000000110

Table 30. Onset of Creep Stress Measurements of Ti-6Al-4V

Temperature °F	Stress KSI	Creep Rate In./In./Hr.
450	76.4	.000000030
450	77.3	NIL
450	78.2	.000001800
450	79.2	NIL
450	80.2	.000000030
450	82.0	NIL
500	76.3	.000000026
500	77.3	NIL
500	81.6	.000000017
500	82.2	.000001500
500	83.2	.000000090
500	83.5	NIL
550	63.5	NIL
550	64.3	.000000032
550	68.2	.000000060
550	69.4	.000000008
550	71.3	NIL
550	72.2	NIL
600	57.3	.000000040
600	58.2	.000000176
600	60.7	NIL
600	62.0	NIL
600	63.8	NIL
600	64.4	.000000037
650	46.5	.000000300
650	47.2	.000000016
650	48.2	.000000110
650	49.3	.000000024
650	54.7	NIL
650	55.3	.000000600

Table 31. Onset of Creep Stress Measurements of Ti-5Al-2 1/2 Sn

Temperature °F	Stress KSI	Creep Rate In./In./Hr.
450	56.2	NIL
450	56.4	.000000013
450	57.3	NIL
450	59.5	.000000022
450	76.8	NIL
450	77.4	.000000280
500	57.8	NIL
500	58.2	NIL
500	73.8	.000000040
500	76.8	.000000050
500	82.5	.000000040
500	83.3	NIL
550	60.2	NIL
550	60.4	.000000008
550	60.8	NIL
550	63.3	NIL
550	80.1	.000000014
550	80.8	Mal-Function
600	57.0	NIL
600	57.3	NIL
600	58.7	.000000130
600	59.3	NIL
600	74.3	.000000240
600	75.0	NIL
650	51.2	NIL
650	52.3	.000000015
650	53.3	NIL
650	55.2	NIL
650	68.3	NIL
650	68.9	.000000015

Table 32. Onset of Creep Stress Measurement of Ti-8Al-1Mo-1V, Ti-6Al-4V and Ti-5Al-2 1/2 Sn Test Temperatures - 450°F Nominal (Sheet 1 of 2)

Elapsed Time Hrs	Front Test Channels								
	Ti-8-1-1 67.8 KSI	Ti-8-1-1 66.8 KSI	Ti-8-1-1 79.3 KSI	Ti-6-4 80.2 KSI	Ti-6-4 76.4 KSI	Ti-6-4 78.2 KSI	Ti-5-2 1/2 56.2 KSI	Ti-5-2 1/2 57.3 KSI	Ti-5-2 1/2 77.4 KSI
0	453.9	455.3	454.9	454.4	453.9	454.7	454.5	455.5	453.3
16	454.5	454.7	454.3	454.0	454.7	455.4	453.5	456.1	453.6
24	453.7	454.5	453.7	453.4	452.1	453.8	453.6	454.7	452.3
40	453.5	454.3	453.7	453.5	453.1	453.7	454.8	456.0	453.9
48	453.9	455.0	454.3	452.8	453.2	454.0	454.0	454.9	453.2
64	453.8	454.4	453.8	453.8	453.5	454.0	454.2	455.2	452.9
72	453.5	454.4	454.5	453.6	453.2	453.6	453.6	455.3	453.7
88	453.7	454.2	453.7	453.7	453.3	453.5	453.6	454.5	452.8
96	453.6	455.7	453.5	453.5	454.2	453.2	453.8	454.7	453.2
112	454.2	454.7	454.2	453.0	453.1	454.5	454.6	455.7	452.1
120	453.9	455.1	453.6	453.8	453.4	454.3	454.4	455.6	452.5
136	452.6	453.4	452.9	452.0	453.2	454.1	453.7	454.4	452.8
144	456.5	455.9	455.3	455.2	455.2	456.0	455.4	456.4	453.2
160	457.1	456.7	456.5	456.8	457.1	456.9	456.8	457.2	455.0

Table 32. Onset of Creep Stress Measurement of Ti-8Al-1Mo-1V, Ti-6Al-4V and Ti-5Al-2 1/2 Sn Test Temperature - 450° F Nominal (Sheet 2 of 2)

Elapsed Time Hrs	Rear Test Channels								
	Ti-8-1-1 66.7 KSI	Ti-8-1-1 65.2 KSI	Ti-8-1-1 78.8 KSI	Ti-6-4 82.0 KSI	Ti-6-4 77.3 KSI	Ti-6-4 79.2 KSI	Ti-5-2 1/2 56.4 KSI	Ti-5-2 1/2 59.5 KSI	Ti-5-2 1/2 76.8 KSI
0	453.5	455.1	453.9	455.6	453.9	453.9	455.3	455.7	455.5
16	451.1	454.2	453.2	456.1	452.9	453.3	454.4	455.0	454.6
24	450.4	453.0	451.9	454.4	451.6	452.0	453.9	453.9	453.6
40	450.6	453.9	454.6	455.3	450.4	450.5	452.7	454.7	453.1
48	452.6	454.3	452.3	454.2	452.4	451.9	454.0	454.9	454.2
64	451.6	453.6	451.7	454.0	452.1	451.7	453.7	455.4	454.3
72	453.6	455.5	453.2	455.7	453.1	453.1	456.4	455.7	453.6
88	452.2	453.6	451.5	453.8	452.5	452.0	453.7	454.4	453.8
96	452.4	454.1	451.6	452.8	452.3	453.3	451.7	454.7	454.2
112	454.0	454.9	452.8	455.4	454.1	452.7	453.7	456.2	455.3
120	453.6	454.3	452.2	455.1	453.7	452.5	453.5	456.2	454.5
136	453.0	455.0	453.4	456.1	452.8	452.5	453.2	456.5	454.7
144	455.4	455.0	456.8	458.9	455.5	456.3	455.4	457.6	456.8
160	456.8	456.9	457.7	459.8	456.7	457.5	456.3	457.9	458.1

Table 33. Onset of Creep Stress Measurement of Ti-8Al-1Mo-1V, Ti-6Al-4V and Ti-5Al-2 1/2 Sn Test Temperature - 500°F Nominal (Sheet 1 of 2)

Elapsed Time Hrs	Front Test Channels								
	Ti-8-1-1 63.2 KSI	Ti-8-1-1 63.2 KSI	Ti-8-1-1 72.3 KSI	Ti-6-4 81.6 KSI	Ti-6-4 76.3 KSI	Ti-6-4 82.2 KSI	Ti-5-2 1/2 57.8 KSI	Ti-5-2 1/2 73.8 KSI	Ti-5-2 1/2 82.5 KSI
0	502.95	504.00	503.30	503.90	503.15	503.20	503.30	504.95	501.50
20	503.95	504.30	504.00	503.75	503.80	504.25	504.25	505.10	501.35
28	502.60	502.80	502.50	502.55	502.60	502.80	502.65	503.35	501.95
44	502.90	503.65	503.10	503.25	503.10	503.45	503.10	505.00	501.55
52	499.45	499.70	499.65	500.05	499.30	499.15	500.05	500.90	499.88
68	500.45	501.05	500.83	500.25	500.40	500.70	500.75	501.90	499.95
76	500.45	500.80	499.30	500.20	500.25	500.80	500.62	502.10	499.65
92	512.00	512.70	511.98	512.95	511.90	511.85	513.00	513.45	513.90
100	500.65	501.90	501.15	501.15	500.90	501.30	502.10	502.63	501.90
116	500.95	501.60	501.25	502.95	501.40	501.45	501.80	502.13	499.60
124	499.60	500.05	500.50	500.50	500.75	500.80	501.25	501.50	501.25
141	500.25	500.85	500.13	500.80	500.30	500.50	501.35	500.50	499.80
169	499.30	500.70	500.85	503.75	505.50	500.70	501.50	501.83	504.45
188	499.30	501.35	502.35	502.55	501.90	502.00	502.05	502.15	502.90
196	495.70	497.40	497.60	497.20	498.25	498.00	497.50	498.60	495.50
212	498.75	500.30	500.55	501.75	500.60	500.65	501.65	501.08	502.25

Table 33. Onset of Creep Stress Measurement of Ti-8Al-1Mo-1V, Ti-6Al-4V and Ti-5Al-2 1/2 Sn Test Temperature - 500°F Nominal (Sheet 2 of 2)

Elapsed Time Hrs	Rear Test Channels								
	Ti-8-1-1 62.2 KSI	Ti-8-1-1 60.7 KSI	Ti-8-1-1 71.8 KSI	Ti-6-4 83.5 KSI	Ti-6-4 77.3 KSI	Ti-6-4 83.2 KSI	Ti-5-2 1/2 58.2 KSI	Ti-5-2 1/2 76.8 KSI	Ti-5-2 1/2 82.5 KSI
0	505.85	509.20	506.25	509.45	506.40	506.10	506.35	507.80	507.25
20	507.00	507.70	506.80	506.55	506.85	507.80	508.15	506.50	507.95
28	502.15	503.05	503.80	503.80	503.05	503.85	503.55	504.10	505.20
44	501.30	501.15	501.38	501.65	501.95	501.00	501.20	503.05	502.75
52	497.95	498.55	498.50	499.48	499.15	500.03	499.00	500.80	500.85
68	499.35	499.30	500.35	499.90	499.90	499.45	499.30	501.20	501.00
76	500.60	500.35	500.65	499.60	500.90	500.70	501.00	501.80	504.70
92	497.45	496.60	499.25	499.25	498.10	497.25	497.60	498.45	499.60
100	494.00	493.75	494.00	494.10	494.55	495.40	493.70	495.35	496.45
116	493.60	494.45	493.95	494.70	494.75	494.85	494.25	496.30	496.05
124	495.05	493.13	494.65	499.60	494.95	494.25	493.10	495.50	495.90
141	494.95	494.75	495.50	498.00	496.05	496.20	497.45	497.05	496.85
169	492.85	492.80	497.65	496.00	495.90	494.15	493.80	495.35	494.80
188	491.80	492.35	495.80	493.75	494.00	493.05	492.45	495.10	494.25
196	492.68	491.40	491.40	494.25	493.25	495.70	497.40	494.75	493.10
212	491.45	496.65	496.60	494.50	492.70	495.58	496.90	494.55	493.50

Table 34. Onset of Creep Stress Measurement of Ti-8Al-1Mo-1V, Ti-6Al-4V and Ti-5Al-2 1/2 Sn Test Temperature - 550°F Nominal (Sheet 1 of 2)

Elapsed Time Hrs	Front Test Channels								
	Ti-8-1-1 70.4 KSI	Ti-8-1-1 60.5 KSI	Ti-8-1-1 68.7 KSI	Ti-6-4 68.2 KSI	Ti-6-4 63.5 KSI	Ti-6-4 71.3 KSI	Ti-5-2 1/2 60.2 KSI	Ti-5-2 1/2 60.8 KSI	Ti-5-2 1/2 80.8 KSI
0	543.70	545.95	546.50	545.95	546.45	546.50	545.90	545.80	546.05
20	543.10	545.45	547.00	547.30	546.55	546.15	546.70	544.40	546.20
40	543.40	545.35	547.10	547.20	546.40	546.70	546.65	546.00	546.20
48	542.95	544.60	545.35	546.15	544.70	545.30	546.45	544.00	545.80
64	544.60	546.00	545.95	546.60	545.75	546.75	546.65	546.50	545.95
72	543.85	545.05	545.50	546.45	545.80	545.10	546.15	546.20	544.80
88	546.15	546.80	548.55	545.90	548.55	548.75	547.93	547.00	547.75
96	544.55	546.15	547.15	546.85	547.40	548.70	548.23	546.70	548.70
112	547.95	548.80	548.83	548.60	549.23	548.50	548.20	548.95	550.05
120	544.05	546.85	548.53	546.80	549.05	548.10	548.40	548.00	550.65
136	544.20	546.35	547.00	548.50	548.25	549.10	548.20	546.85	551.45
144	543.55	545.90	543.38	547.88	547.10	547.75	546.95	546.40	548.45
160	546.85	546.95	548.85	550.50	549.35	547.50	547.30	546.43	550.75
184	547.25	550.00	550.50	551.70	550.60	550.65	550.05	550.40	552.30
208	547.30	549.65	550.00	551.40	550.05	550.50	551.15	550.10	548.80

Table 34. Onset of Creep Stress Measurement of Ti-8Al-1Mo-1V, Ti-6Al-4V and Ti-5Al-2 1/2 Sn Test Temperature - 550°F (Sheet 2 of 2)

Elapsed Time Hrs	Rear Test Channels								
	Ti-8-1-1 69.4 KSI	Ti-8-1-1 59.0 KSI	Ti-8-1-1 68.2 KSI	Ti-6-4 69.4 KSI	Ti-6-4 64.3 KSI	Ti-6-4 72.2 KSI	Ti-5-2 1/2 60.4 KSI	Ti-5-2 1/2 63.3 KSI	Ti-5-2 1/2 80.1 KSI
0	546.50	545.90	546.55	547.40	548.20	546.50	545.90	545.80	546.05
20	546.15	546.70	545.05	547.55	549.75	546.15	546.70	544.40	546.20
40	546.70	546.65	546.40	545.60	548.50	546.70	546.65	546.00	546.20
48	545.30	546.45	547.20	547.15	548.25	545.30	546.45	544.00	545.80
64	546.75	546.65	544.00	544.15	545.15	546.75	546.65	506.49	545.95
72	545.10	546.15	547.30	547.55	548.80	545.10	546.15	546.18	544.80
88	548.75	547.95	547.45	548.05	549.05	548.75	547.93	547.00	547.23
96	548.70	548.25	547.35	547.75	548.70	548.70	548.25	546.70	548.70
112	548.50	548.20	544.85	547.10	549.40	548.50	548.20	548.95	550.03
120	548.10	548.40	546.20	548.75	548.15	548.10	548.40	547.98	550.65
136	549.10	549.20	546.85	547.83	549.15	549.10	548.20	546.85	551.45
144	547.75	546.95	547.40	547.55	548.85	547.13	546.95	546.40	548.45
160	547.50	547.30	548.10	548.45	550.25	547.50	547.30	546.45	550.75
184	550.65	550.05	549.80	549.93	551.15	550.65	550.05	550.40	552.30
208	550.50	551.15	550.90	551.55	550.75	550.48	551.15	550.10	548.80

Table 35. Onset of Creep Stress Measurement of Ti-8Al-1Mo-1V, Ti-6Al-4V and Ti-5Al-2 1/2 Sn Test Temperature - 600°F Nominal (Sheet 1 of 2)

Elapsed Time Hrs	Front Test Channels								
	Ti-8-1-1 67.3 KSI	Ti-8-1-1 66.8 KSI	Ti-8-1-1 69.0 KSI	Ti-6-4 60.7 KSI	Ti-6-4 57.3 KSI	Ti-6-4 64.4 KSI	Ti-5-2 1/2 57.3 KSI	Ti-5-2 1/2 57.0 KSI	Ti-5-2 1/2 75.0 KSI
0	595.70	597.90	597.85	599.40	599.20	598.30	598.60	598.30	596.65
26	593.75	597.00	597.05	598.40	598.35	597.70	598.90	597.15	594.75
56	591.15	594.25	593.35	594.15	595.35	594.25	595.15	594.60	594.05
72	594.45	597.95	597.18	598.65	598.50	598.35	599.20	597.05	594.15
80	592.55	595.15	594.65	595.90	592.95	592.15	592.95	591.20	595.50
96	594.85	597.50	597.35	598.20	598.15	597.50	597.83	597.10	599.70
114	597.20	598.00	598.70	599.05	600.20	600.05	598.93	599.00	599.45
130	599.29	600.25	601.15	601.70	601.25	601.49	601.50	601.20	600.90
138	598.00	599.05	599.40	599.45	600.00	599.50	599.05	598.30	599.35
154	599.05	600.30	600.85	600.65	600.60	600.65	600.28	599.15	600.70
162	597.10	598.40	598.23	598.25	598.03	596.05	596.58	595.60	596.40

Table 35. Onset of Creep Stress Measurement of Ti-8Al-1Mo-1V, Ti-6Al-4V and Ti-5Al-2 1/2 Sn Test Temperature - 600°F Nominal (Sheet 2 of 2)

Elapsed	Rear Test Channels								
Time Hrs	Ti-8-1-1 66.7 KSI	Ti-8-1-1 65.0 KSI	Ti-8-1-1 68.8 KSI	Ti-6-4 62.0 KSI	Ti-6-4 58.2 KSI	Ti-6-4 63.8 KSI	Ti-5-2 1/2 58.7 KSI	Ti-5-2 1/2 59.3 KSI	Ti-5-2 1/2 74.3 KSI
0	593.65	592.35	593.50	595.85	595.10	591.40	593.40	591.75	591.45
26	593.50	592.55	592.85	594.40	595.20	592.45	593.80	592.30	591.20
56	592.20	590.90	591.55	593.95	594.80	591.15	592.30	591.10	589.80
72	593.65	592.50	593.65	594.10	594.60	591.45	593.15	592.35	591.50
80	587.60	587.90	587.33	588.50	589.00	585.70	587.60	585.45	585.80
96	592.80	592.40	593.15	593.05	594.65	591.80	592.85	592.05	591.50
114	598.65	597.70	598.95	599.43	600.30	599.60	599.20	597.90	597.93
130	601.45	601.45	601.35	601.30	601.10	599.85	600.60	598.35	596.80
138	601.40	601.50	601.90	599.80	600.95	600.60	600.30	598.70	598.45
154	601.95	601.73	602.03	599.85	601.10	599.95	599.50	598.90	597.85
162	600.20	600.70	597.35	599.10	600.35	598.90	601.05	601.65	601.89

Table 36. Onset of Creep Stress Measurement of Ti-8Al-1Mo-1V, Ti-6Al-4V and Ti-5Al-2 1/2 Sn Test Temperature - 650°F Nominal (Sheet 1 of 2)

Elapsed Time Hrs	Front Test Channels								
	Ti-8-1-1 52.6 KSI	Ti-8-1-1 49.3 KSI	Ti-8-1-1 55.6 KSI	Ti-6-4 48.2 KSI	Ti-6-4 46.5 KSI	Ti-6-4 55.3 KSI	Ti-5-2 1/2 51.2 KSI	Ti-5-2 1/2 53.3 KSI	Ti-5-2 1/2 68.9 KSI
0	658.75	658.85	657.90	658.55	655.80	654.75	653.78	654.40	656.00
24	652.70	653.75	653.70	655.53	654.70	654.50	654.40	653.60	655.85
32	650.10	652.20	651.35	653.35	652.53	651.90	651.70	650.70	652.45
48	649.00	648.50	651.45	652.90	651.75	651.18	651.33	651.10	651.10
56	648.50	647.45	648.15	649.10	648.60	648.65	648.25	647.70	648.75
72	649.20	650.95	649.85	652.05	652.07	652.00	651.80	650.90	652.45
96			Recorder Non-Operative						
114			Recorder Non-Operative						
133			Recorder Non-Operative						
156			Recorder Non-Operative						
178	647.40	649.00	649.33	650.95	650.30	650.25	650.55	649.65	649.95
186	647.60	649.80	649.43	651.90	651.70	650.80	649.85	651.20	652.25
194	647.33	649.58	650.05	650.75	650.80	650.90	659.55	651.08	650.15
210	646.88	646.93	650.15	650.78	649.75	650.58	649.75	650.65	650.10
236	646.65	648.50	648.45	649.90	649.60	649.15	647.70	648.10	648.75

Table 36. Onset of Creep Stress Measurement of Ti-8Al-1Mo-1V, Ti-6Al-4V and Ti-5Al-2 1/2 Sn Test Temperature -650°F Nominal (Sheet 2 of 2)

Elapsed Time Hrs	Rear Test Channels								
	Ti-8-1-1 57.1 KSI	Ti-8-1-1 58.5 KSI	Ti-8-1-1 64.6 KSI	Ti-6-4 51.2 KSI	Ti-6-4 55.8 KSI	Ti-6-4 60.7 KSI	Ti-5-2 1/2 57.7 KSI	Ti-5-2 1/2 62.1 KSI	Ti-5-2 1/2 61.0 KSI
0	647.15	646.70	647.40	648.45	646.70	645.95	646.15	645.65	646.65
24	649.50	650.95	649.95	650.15	649.65	649.15	649.00	648.70	648.93
32	644.30	644.05	644.60	645.30	646.50	643.70	644.50	644.13	642.10
48	646.90	645.95	645.50	643.90	644.30	642.55	643.95	643.35	642.78
56	646.00	646.05	645.90	645.65	646.65	644.10	644.00	644.50	643.45
72	651.60	651.45	650.20	653.55	653.65	651.55	651.80	650.75	650.25
96				Recorder Non-Operative					
114				Recorder Non-Operative					
133				Recorder Non-Operative					
156				Recorder Non-Operative					
178	648.20	648.60	649.95	650.15	650.20	646.35	647.65	647.25	645.50
186	648.35	649.10	649.30	650.10	650.55	647.40	649.00	648.00	646.35
194	647.60	648.35	649.05	649.40	650.20	648.65	646.20	646.90	646.15
210	647.75	647.80	648.60	648.60	650.65	646.90	647.40	646.95	645.45
236	646.60	647.30	648.05	648.80	649.85	646.60	647.30	646.85	644.60

Table 37. Load System Calibration Data

Dead Weight Lbs.	Load Transmission System Loads								
	System 1	System 2	System 3	System 4	System 5	System 6	System 7	System 8	System 9
0	0	0	0	0	0	0	0	0	0
20	369.6	330.4	361.2	375.2	341.6	392.0	333.2	364.0	492.8
40	719.6	641.2	711.2	764.4	666.4	764.4	679.2	753.2	960.4
60	1078.0	971.6	1069.6	1153.6	1010.8	1108.8	1061.2	1066.8	1394.4
80	1419.6	1310.4	1442.0	1548.4	1358.0	1458.8	1428.0	1419.6	1780.8
100	1806.0	1646.4	1794.8	1918.0	1674.4	1727.6	1750.0	1713.6	2200.8
120	2198.0	2018.8	2167.2	2335.2	2052.4	2077.6	2142.0	2080.4	2618.0
140	2590.0	2394.0	2559.2	2760.8	2450.0	2436.0	2356.8	2430.4	3021.2
160	2979.2	2788.8	2931.6	3175.2	2850.4	2819.6	2923.2	2819.6	3424.4
180	3374.0	3180.8	3348.8	3612.0	3253.6	3206.0	3320.8	3206.0	3824.8
200	3780.0	3600.8	3763.2	4057.2	3656.8	3584.0	3721.2	3609.2	4228.0
220	4180.4	4015.2	4180.4	4505.2	4102.0	3978.8	4132.8	4009.6	4614.4
240	4600.4	4463.2	4592.0	4989.6	4544.4	4376.4	4541.6	4438.0	5003.6
260	5023.2	4891.2	5012.0	5482.4	4978.4	4771.2	4970.0	4852.4	5381.6
280	5460.0	5359.2	5437.6	5950.0	5460.0	5171.6	5392.8	5306.0	5773.6
300	5585.6	5798.8	5871.6	6445.6	5924.8	5588.8	5824.0	5475.6	6134.8
320	6325.2	6235.6	6334.8	6958.0	6431.6	6000.4	6269.2	6185.2	6512.8
340	6762.0	6683.6	6798.4	7411.6	6963.6	6384.0	6720.0	6661.2	6904.8

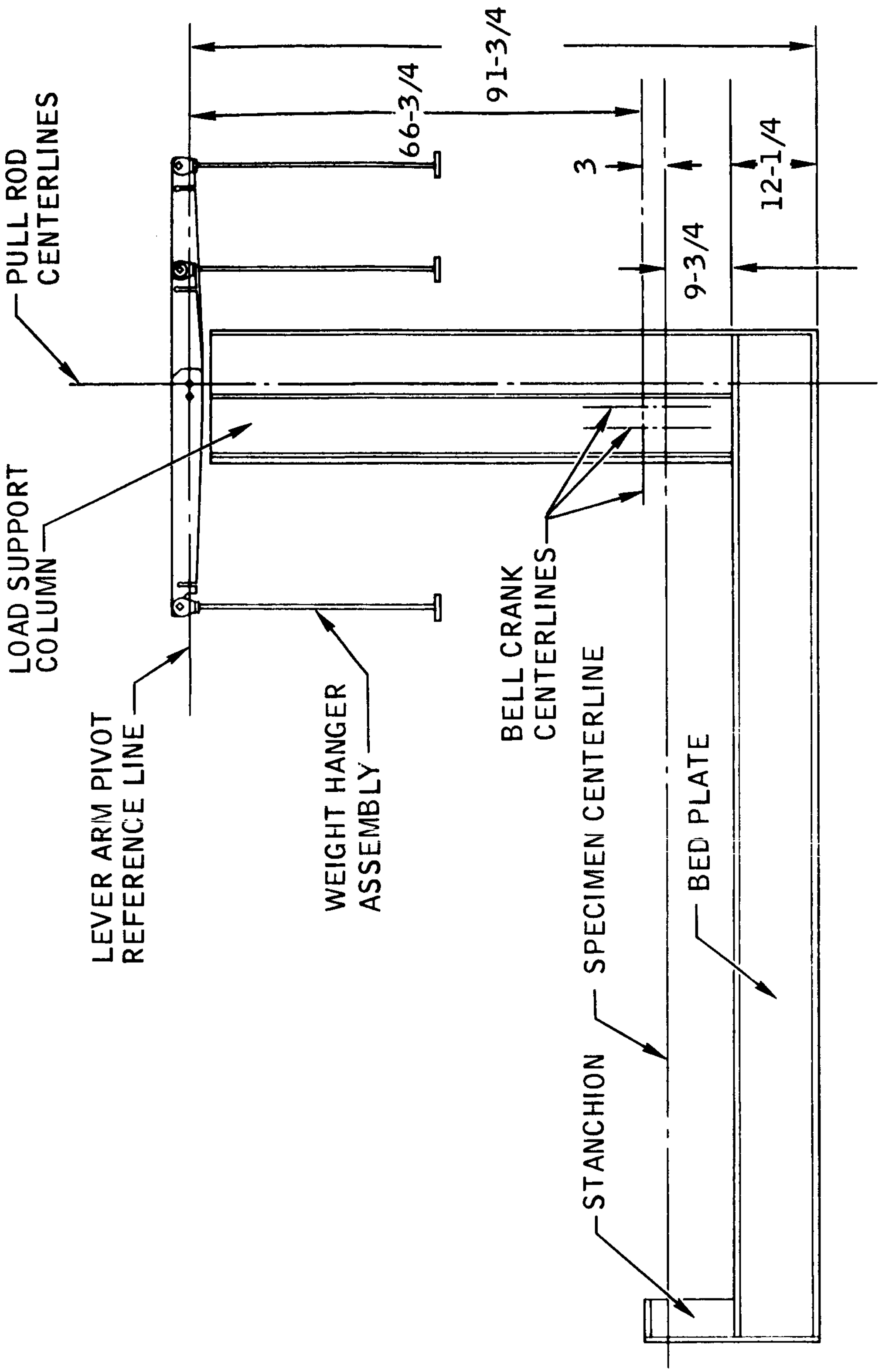


Figure 1. Creep Test Frame General Arrangement (Elevation)

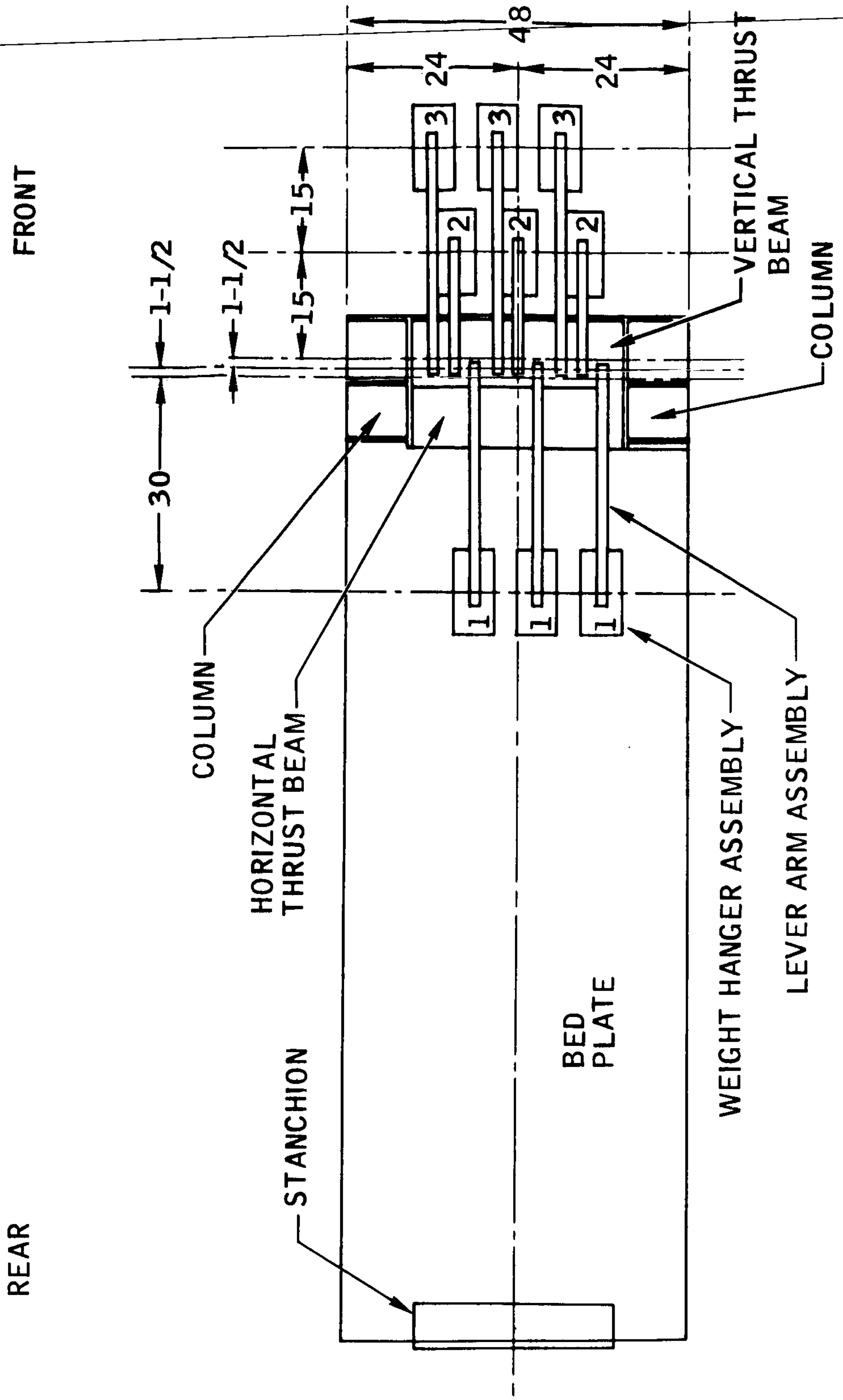


Figure 2. Creep Test Frame General Arrangement (Plan)

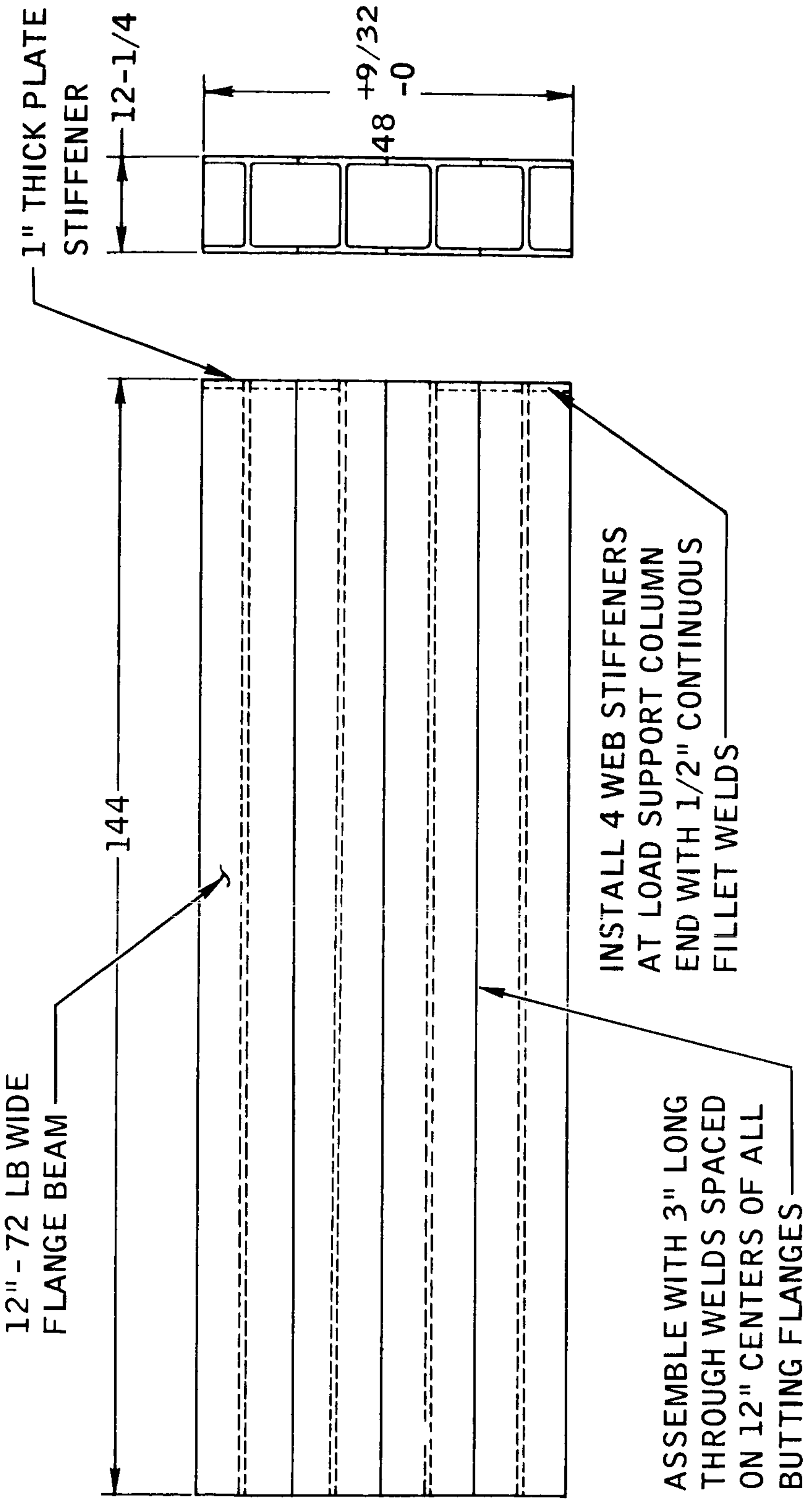


Figure 3. Bed Plate Assembly

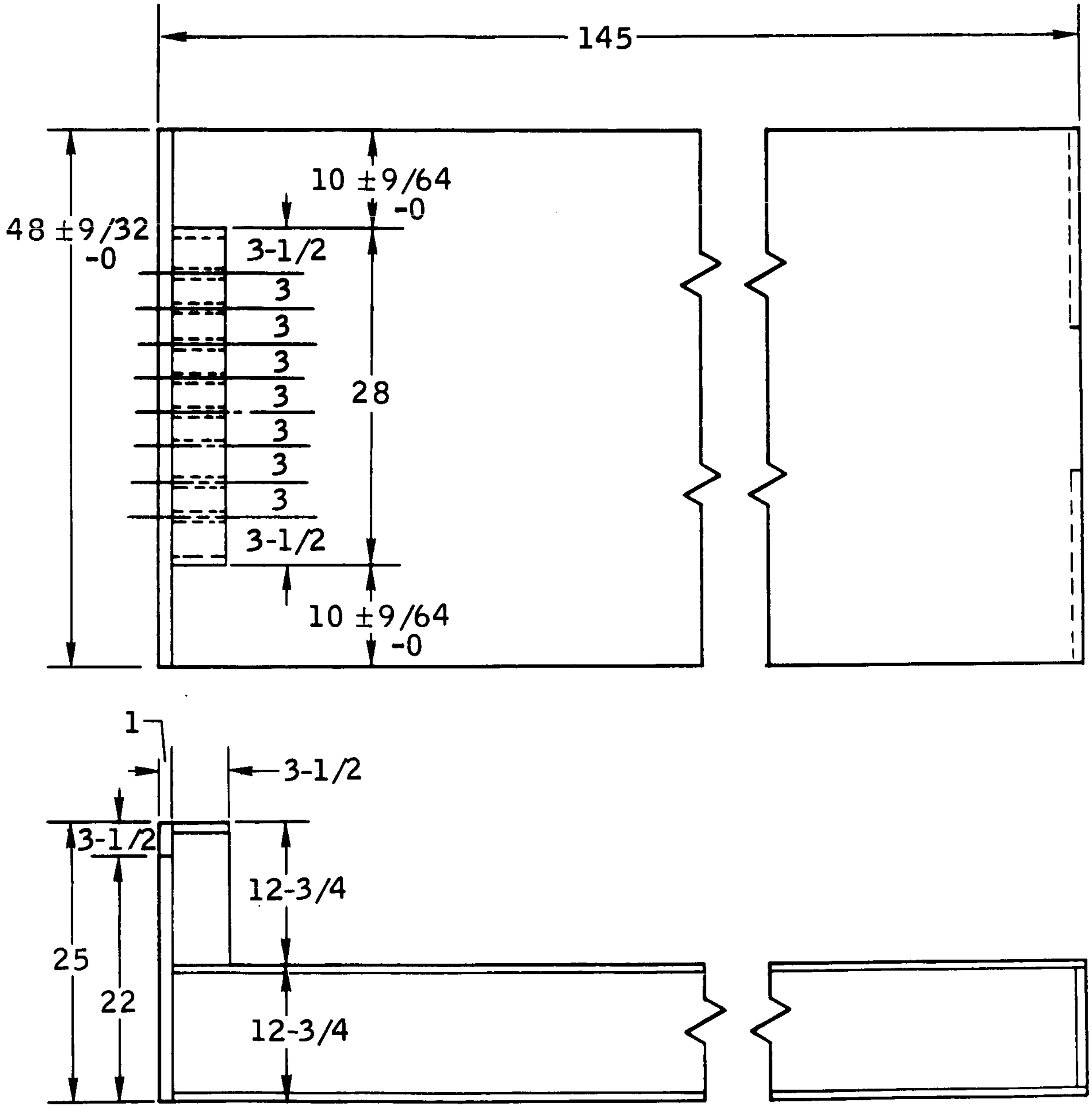


Figure 4. Stanchion Assembly

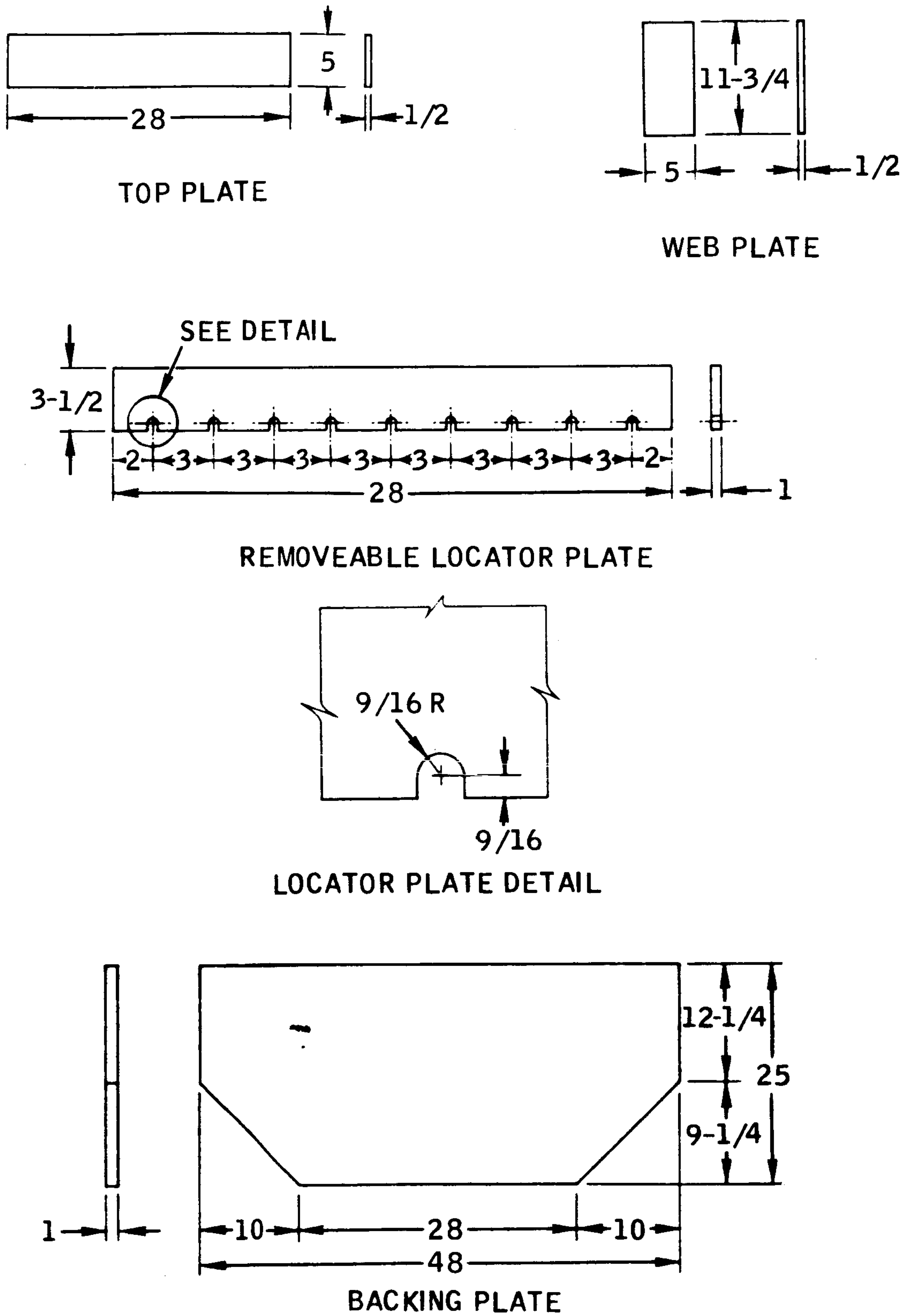
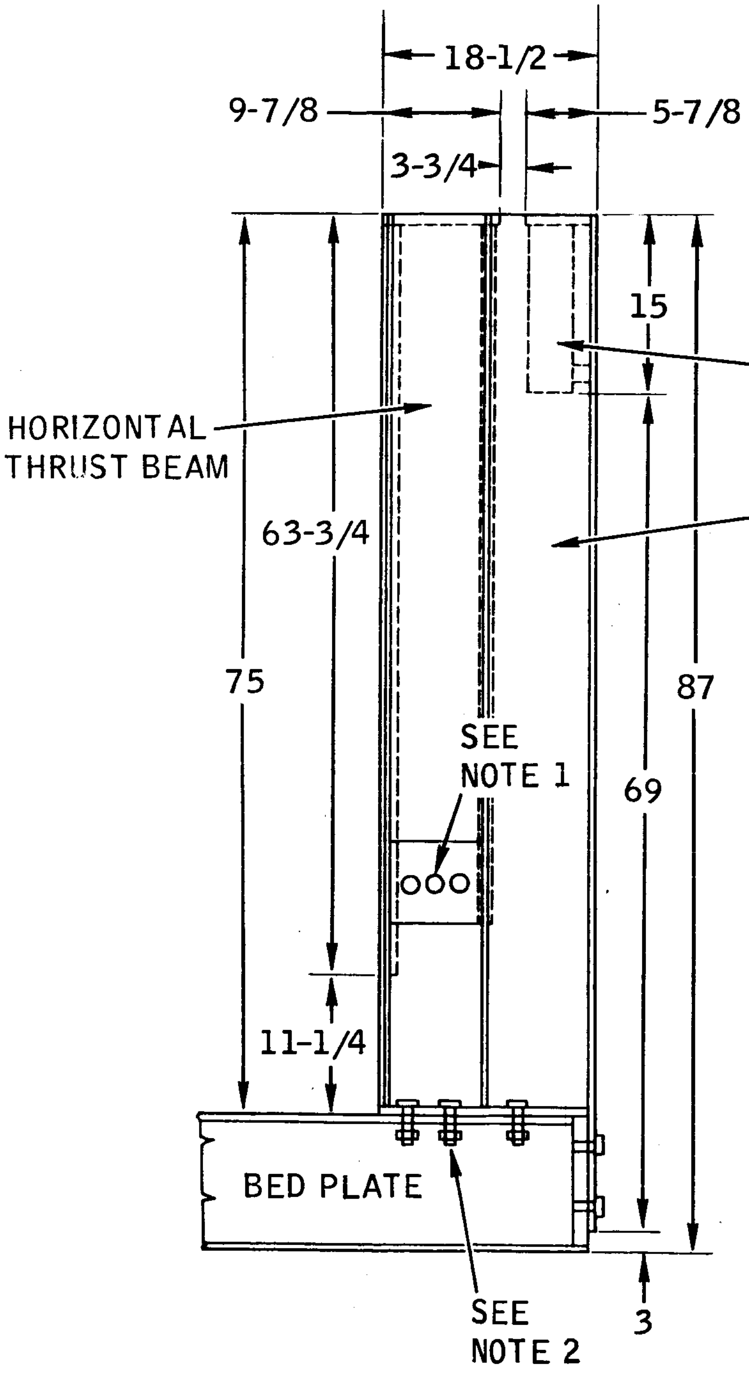


Figure 5. Stanchion Details



VERTICAL THR
REF. FIGURE 1
ATTACH TO BE
COLUMNS WITH
WELD ALL ARO

LEFT HAND
BEAM SUPP
REF. FIGUR
DETAIL

NOTE 1

ASSEMBLE HORIZONTAL THRUST BEAM TO BEAM SUPPORT COLUMS WITH PRESS FITTED AND PRESSED-IN 1-3/8 DIA x 3 LNG. C.R.S. DOWELS (BOTH SIDES)

NOTE 2

ASSEMBLE BEAM SUPPORT COLUMNS TO BED PLATE WITH 3/4 - 16 N.F. FITTED BOLTS WITH 1-1/4 FULL BEARING ON BOLT SHANKS. REF. FIGURE 12 AND 13 DETAIL FOR HOLE LOCATION.

2

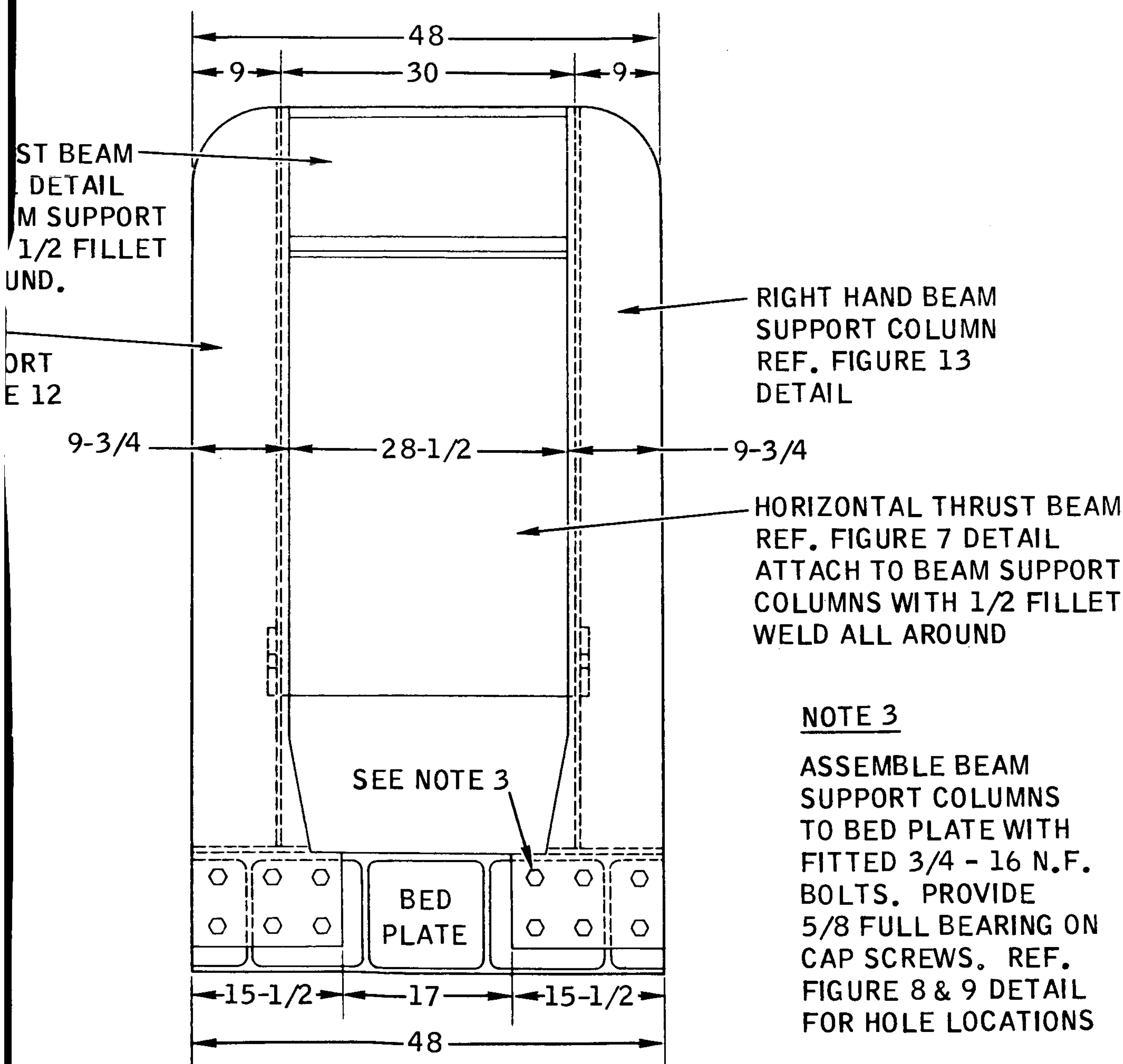


Figure 6. Load Support Column Assembly and Bed Plate Attachment

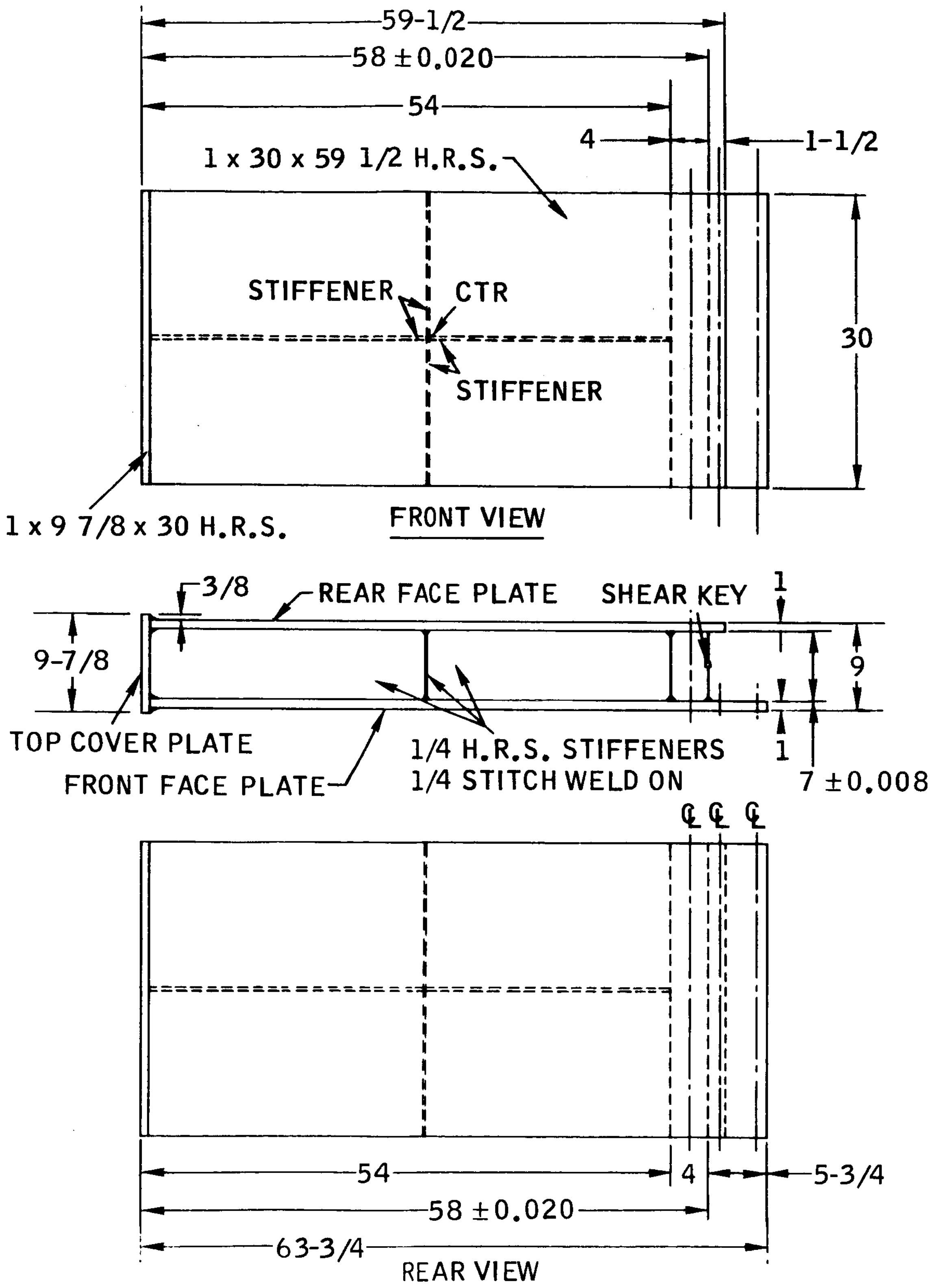


Figure 7. Horizontal Thrust Beam Sub-Assembly

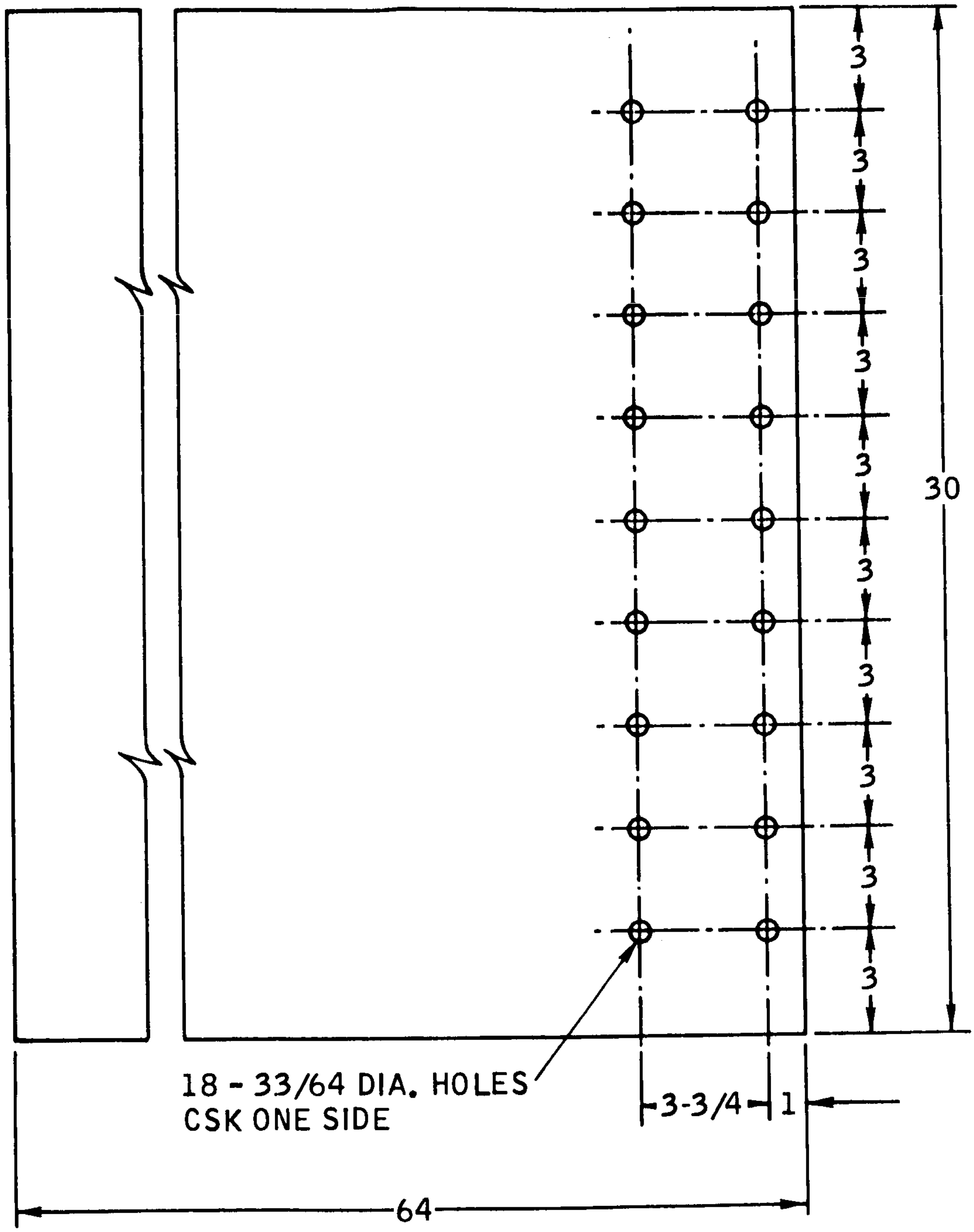


Figure 8. Horizontal Thrust Beam Front Face Plate Detail

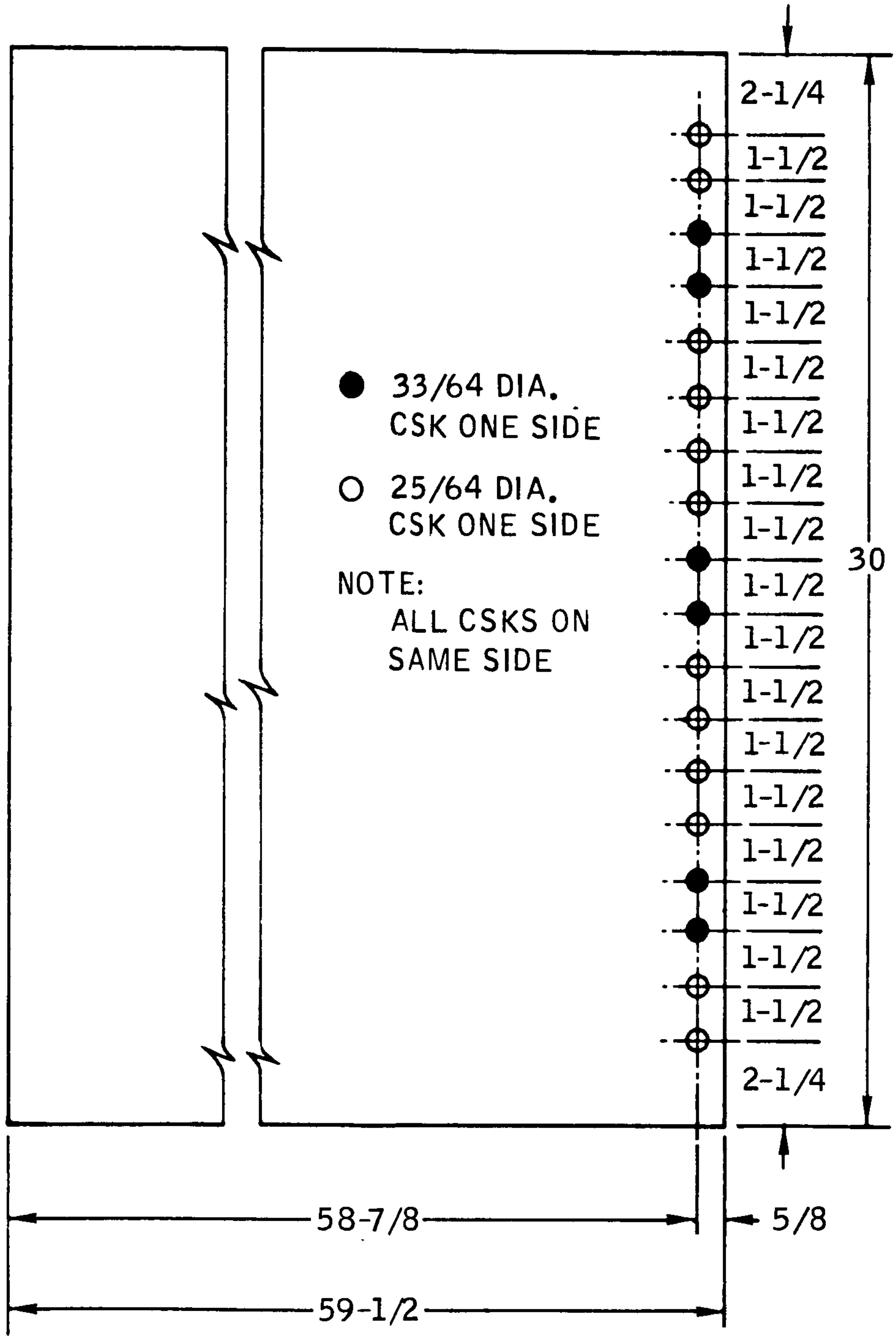


Figure 9. Horizontal Thrust Beam Rear Face Plate Detail

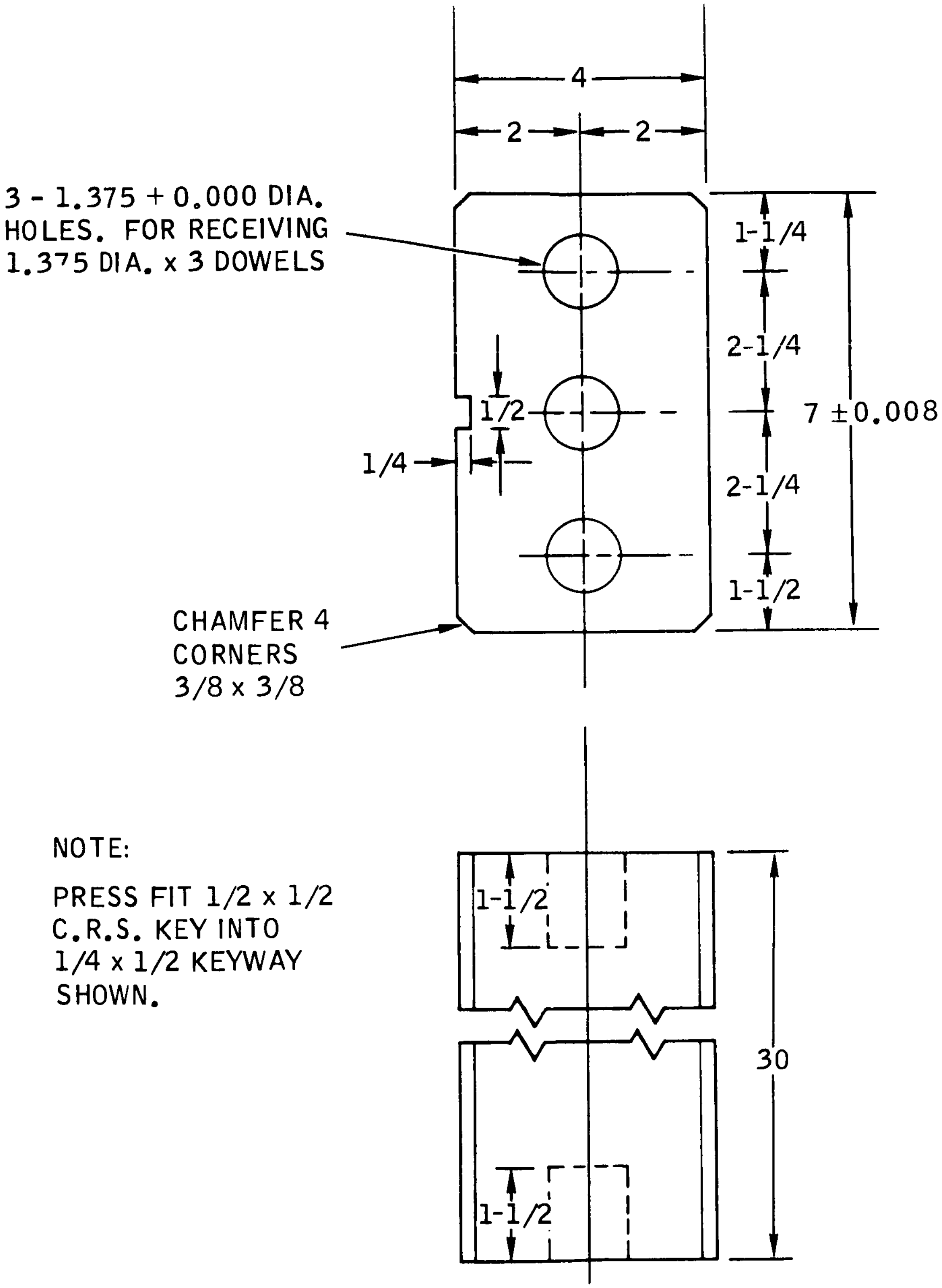


Figure 10. Horizontal Thrust Beam Thrust Bar

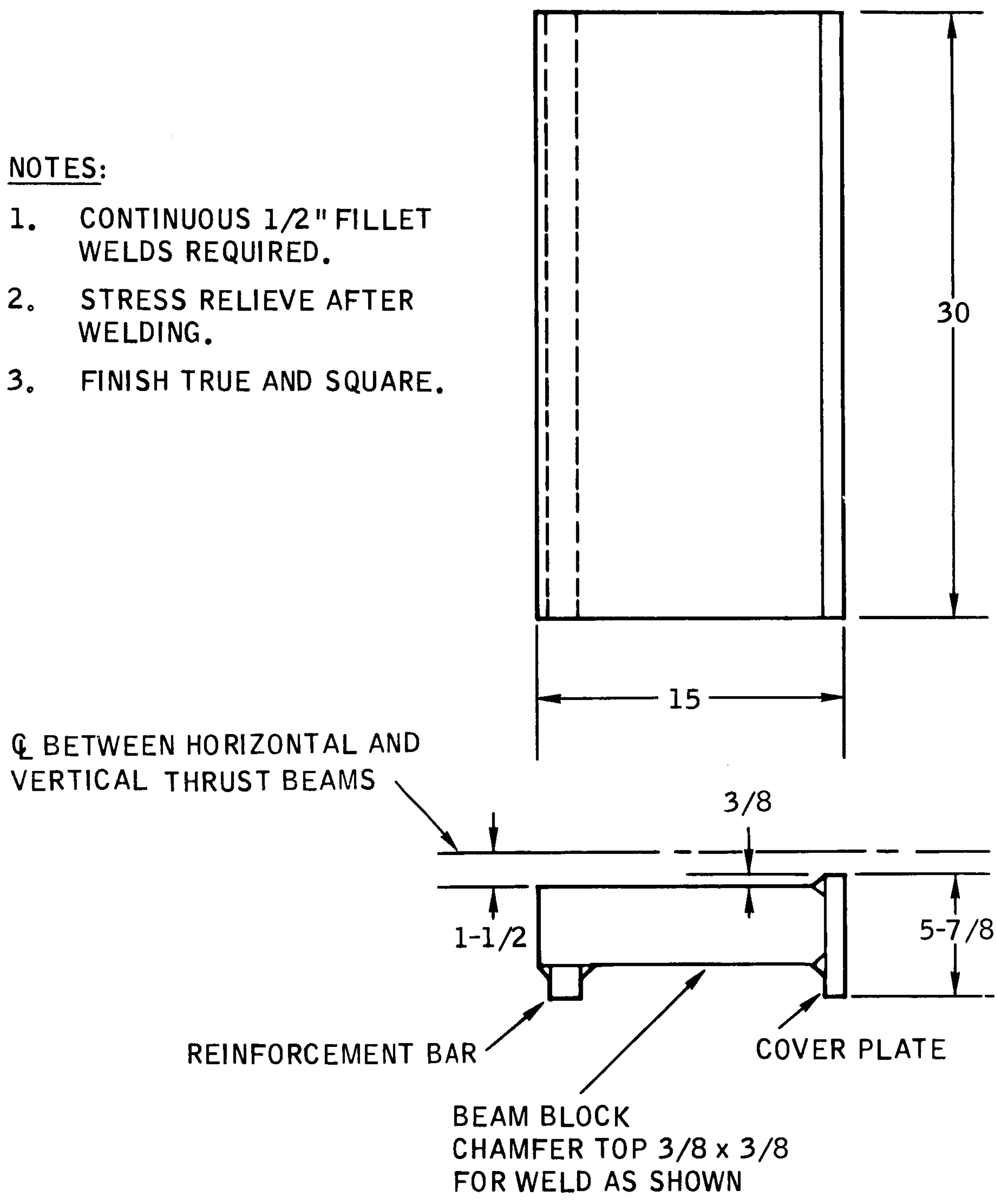


Figure 11. Vertical Thrust Beam

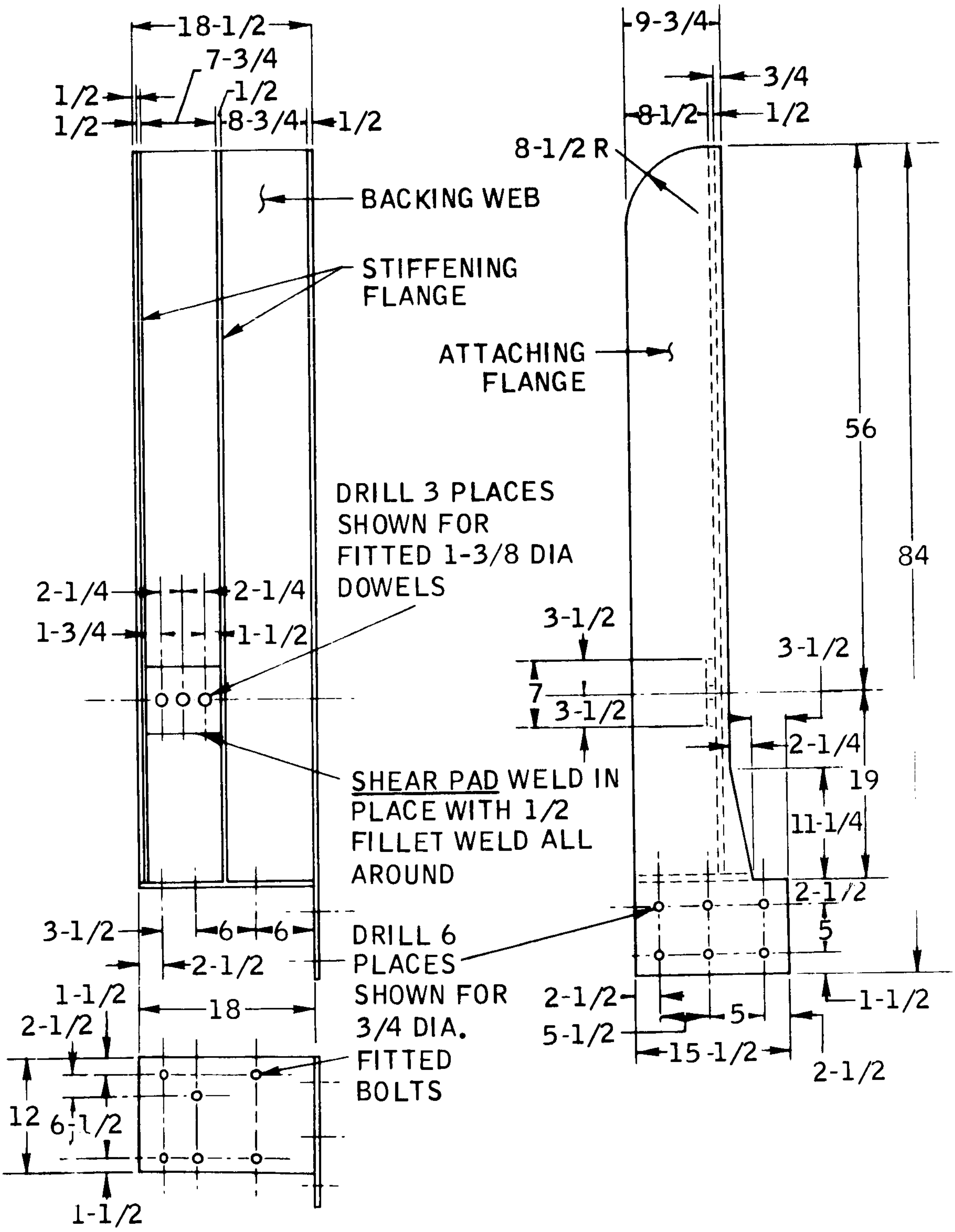


Figure 12. Beam Support Column - Left Hand

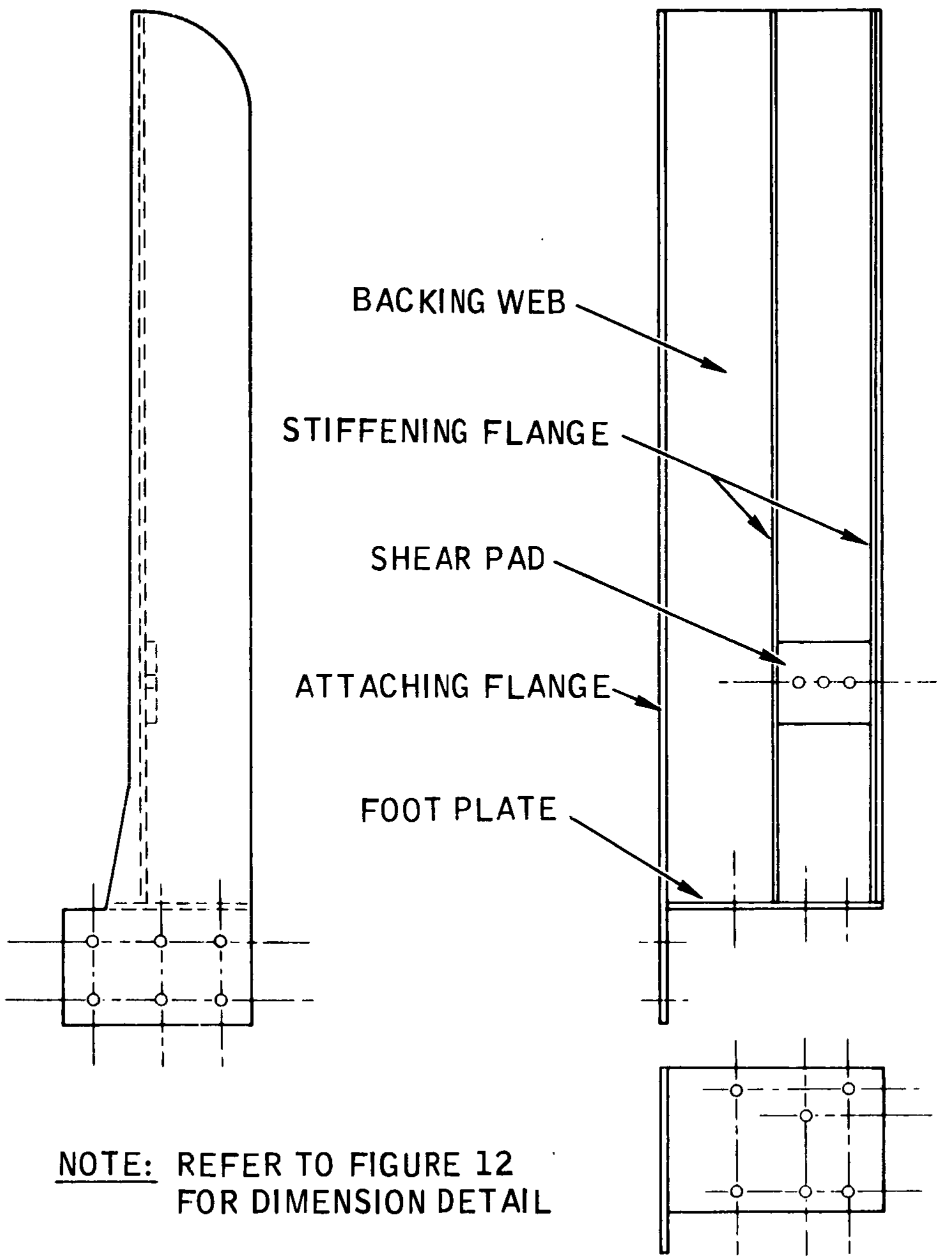


Figure 13. Beam Support Column - Right Hand (Arrangement)

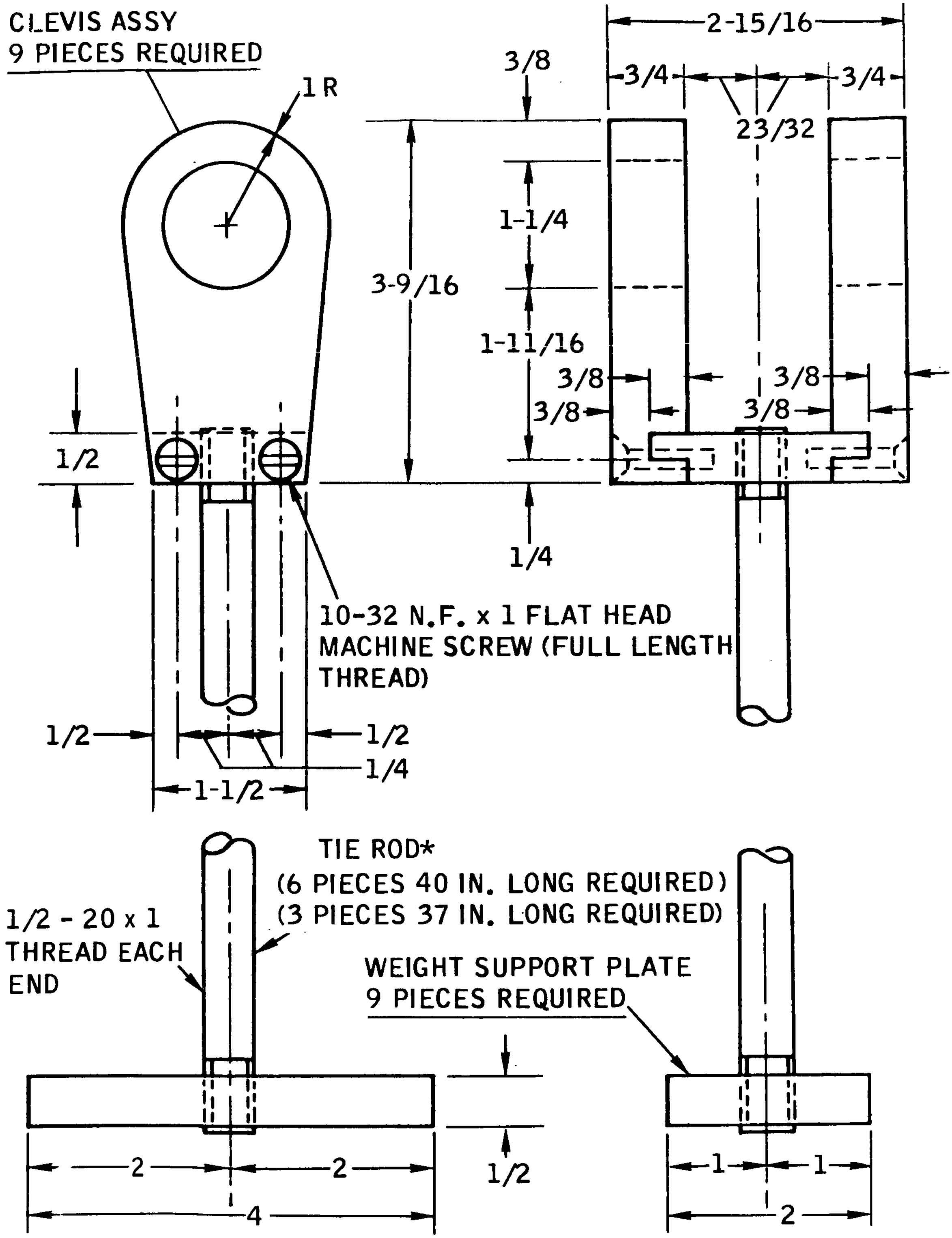
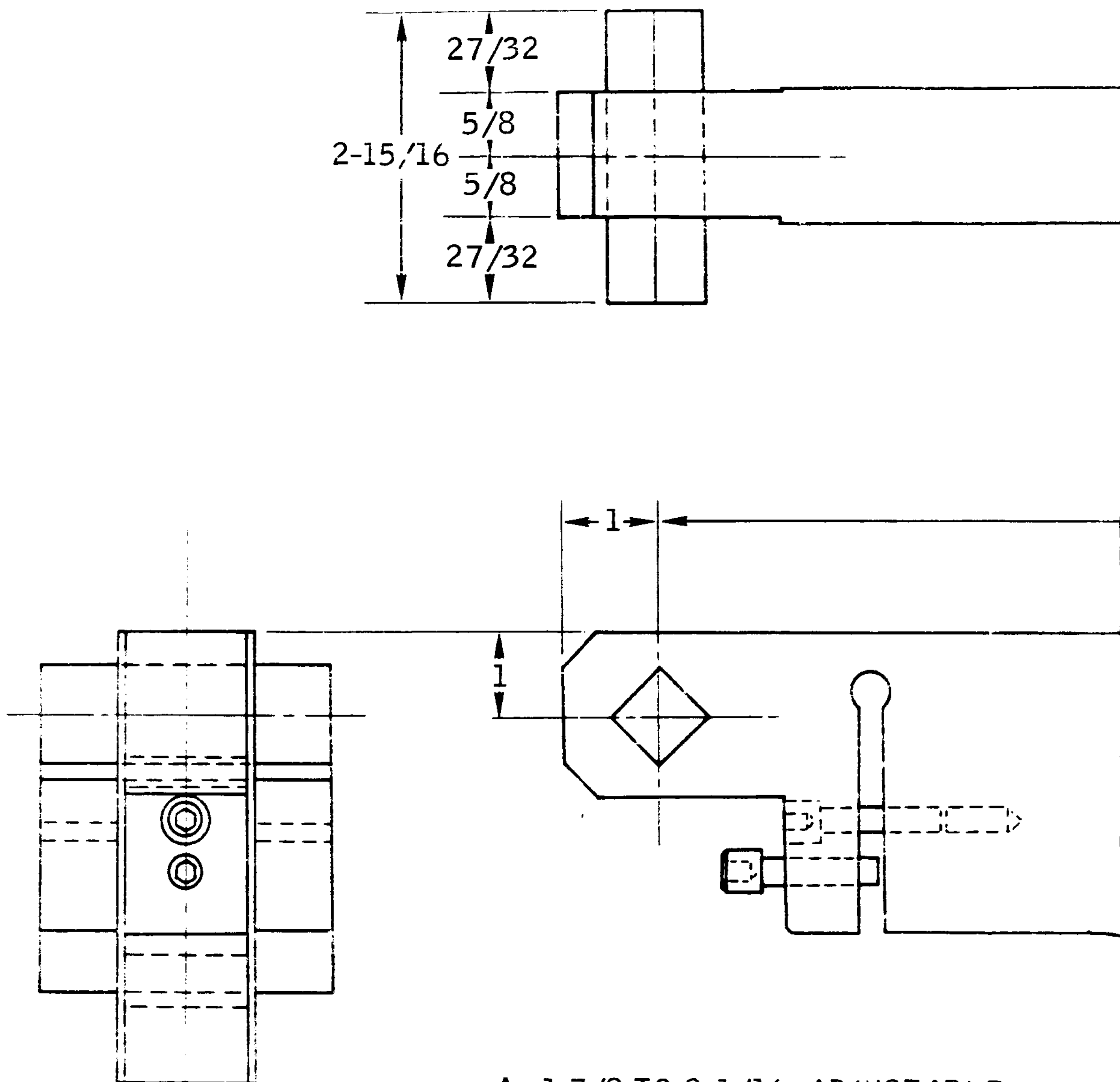


Figure 14. Weight Hanger Assembly

*See also Page 37.

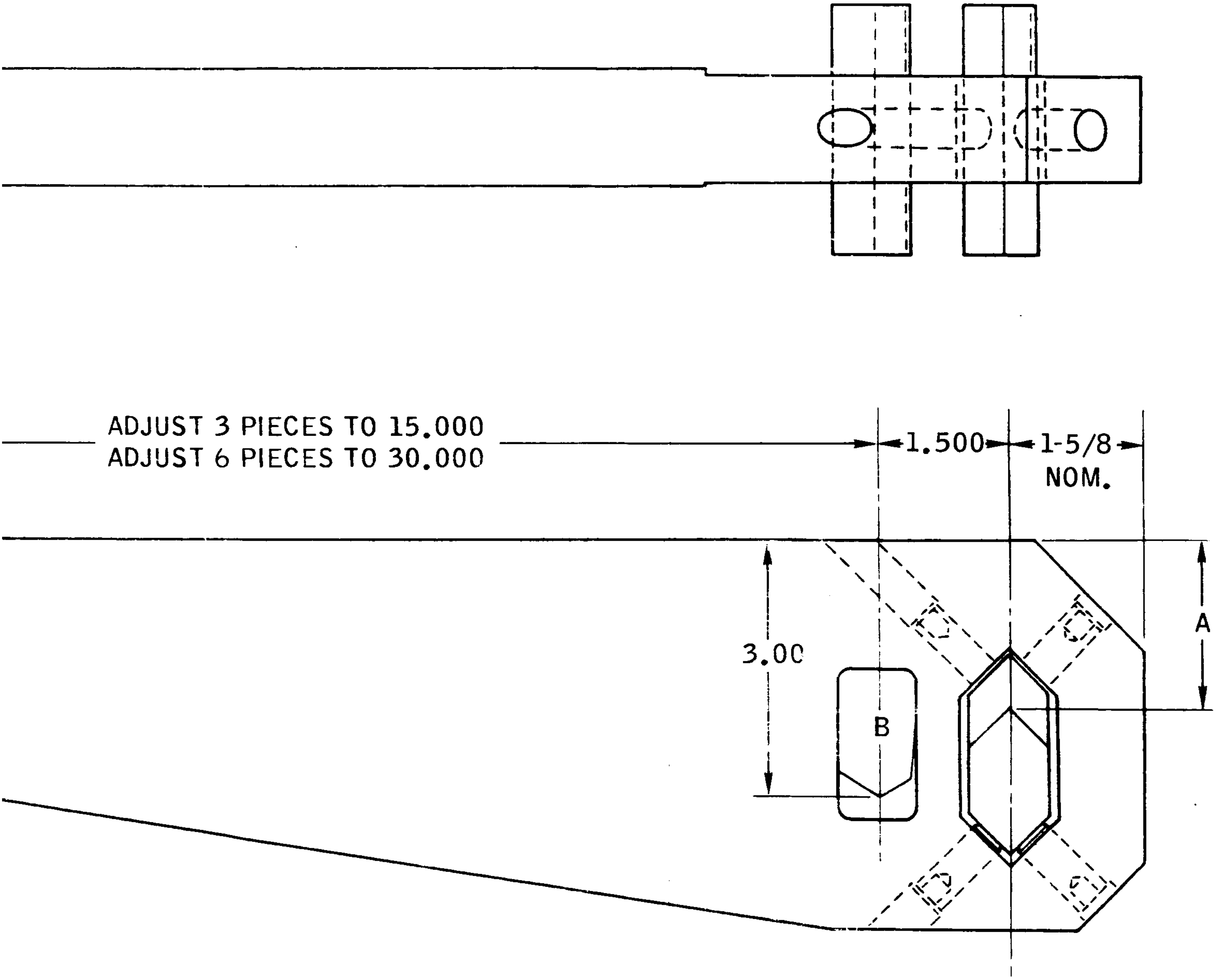
F1



A. 1-7/8 TO 2-1/16 ADJUSTABLE

B. INSTALL FULCRUM PIVOTS IN THREE 3
ARMS AS SHOWN. REVERSE HORIZON
THREE 34-IN.-LONG AND THREE 19-IN.-

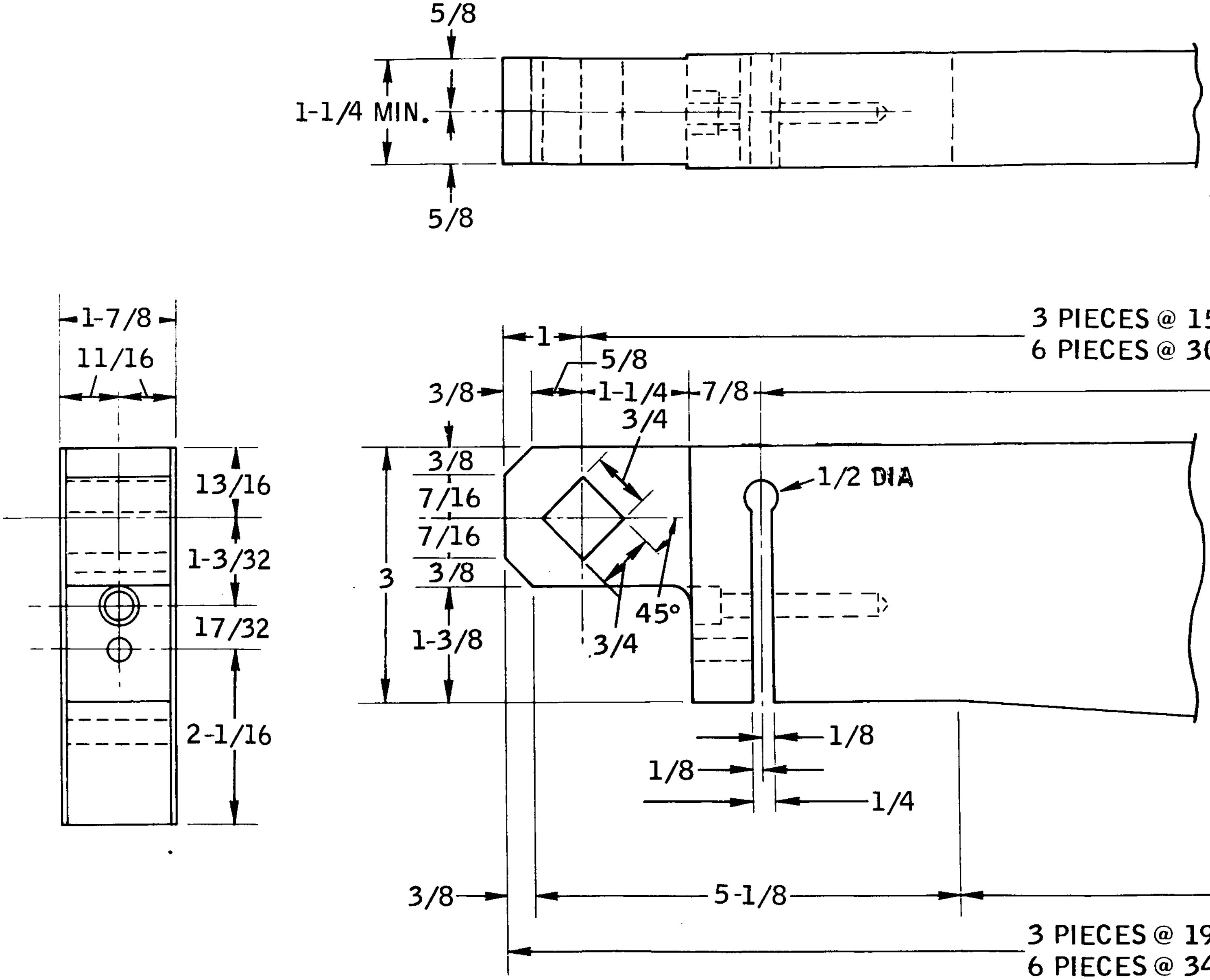
F 2



4-IN.-LONG LEVER
AL POSITIONING IN
LONG LEVER ARMS.

Figure 15. Lever Arm Assembly

B 1



5/8
1-1/4 MIN.
5/8
1-7/8
11/16
13/16
1-3/32
17/32
2-1/16
1
5/8
3/8
1-1/4
7/8
3/4
3/8
7/16
7/16
3/8
3
1-3/8
1/2 DIA
45°
3/4
1/8
1/8
1/4
3/8
5-1/8
3 PIECES @ 15
6 PIECES @ 30
3 PIECES @ 19
6 PIECES @ 34

B 2

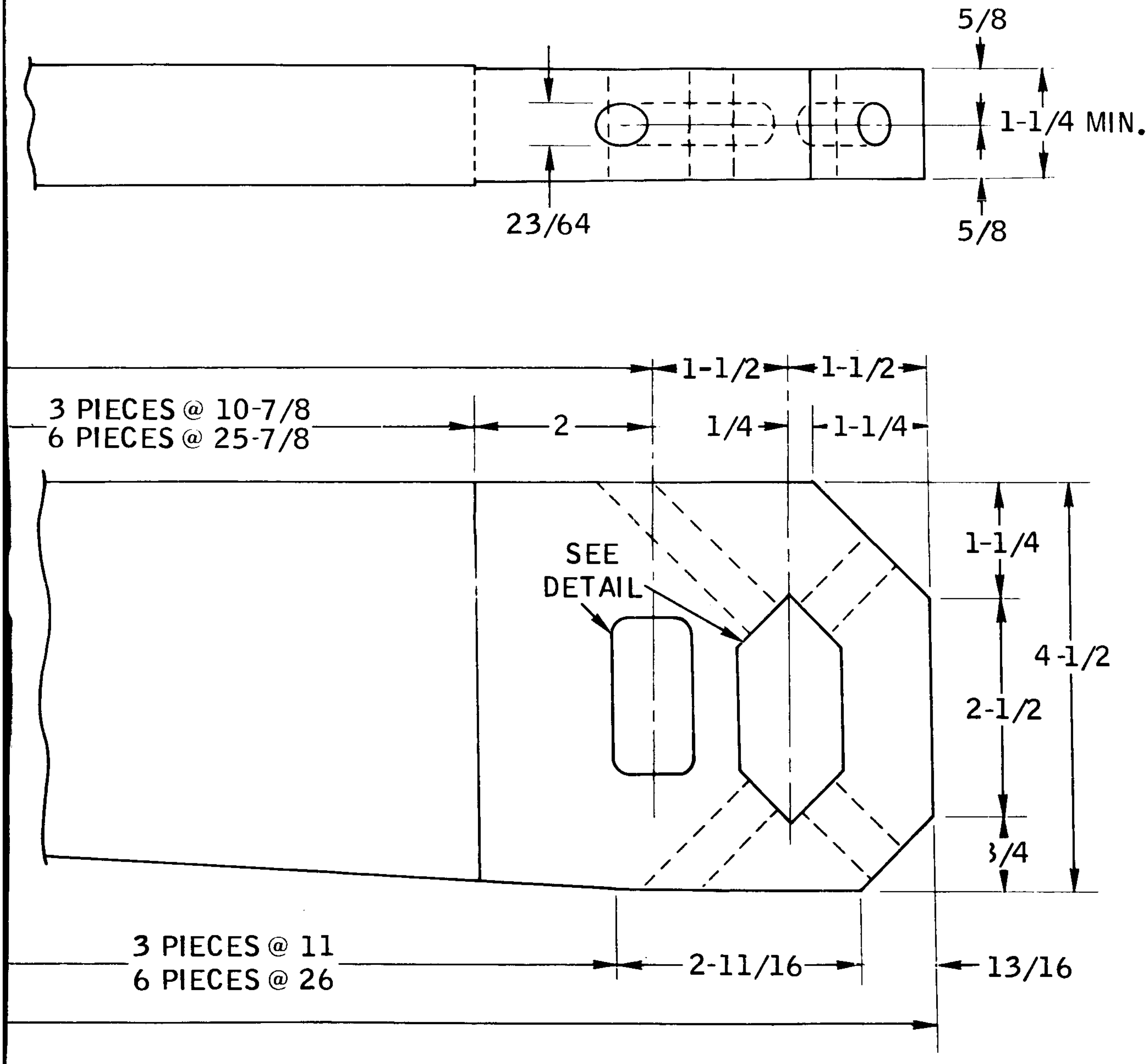
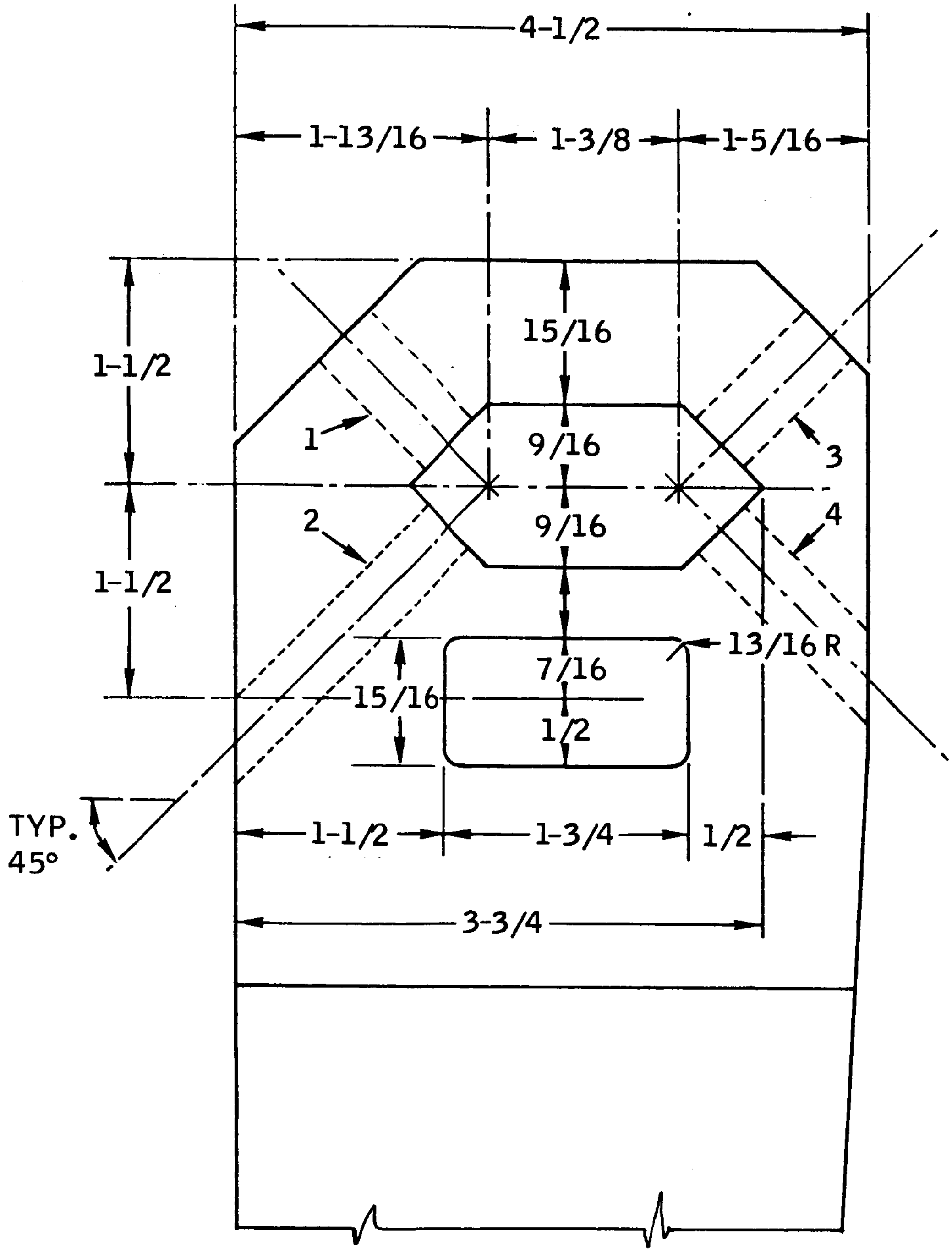


Figure 16. Lever Arm



1, 2 - DRILL AND TAP 1/2 - 20 COUNTERBORE AS REQUIRED TO START TAP - 1", FULL THREAD REQUIRED.

3, 4 - DRILL AND TAP 5/8 - 18 COUNTERBORE AS REQUIRED TO START TAP - 1", FULL THREAD REQUIRED.

Figure 17. Lever Arm Detail

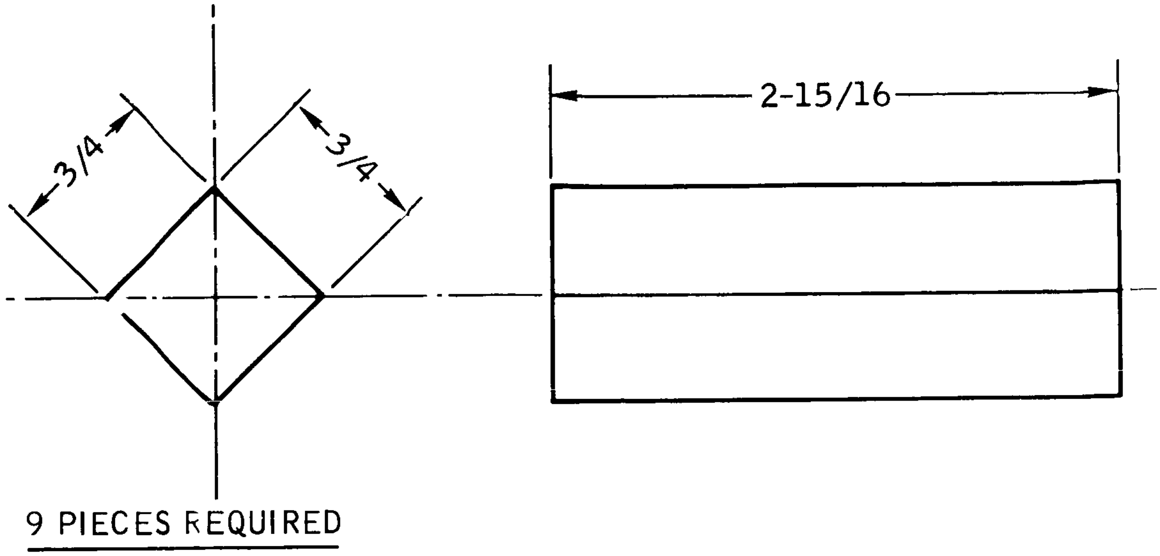


Figure 18. Weight Hanger Knife Edge Pivot

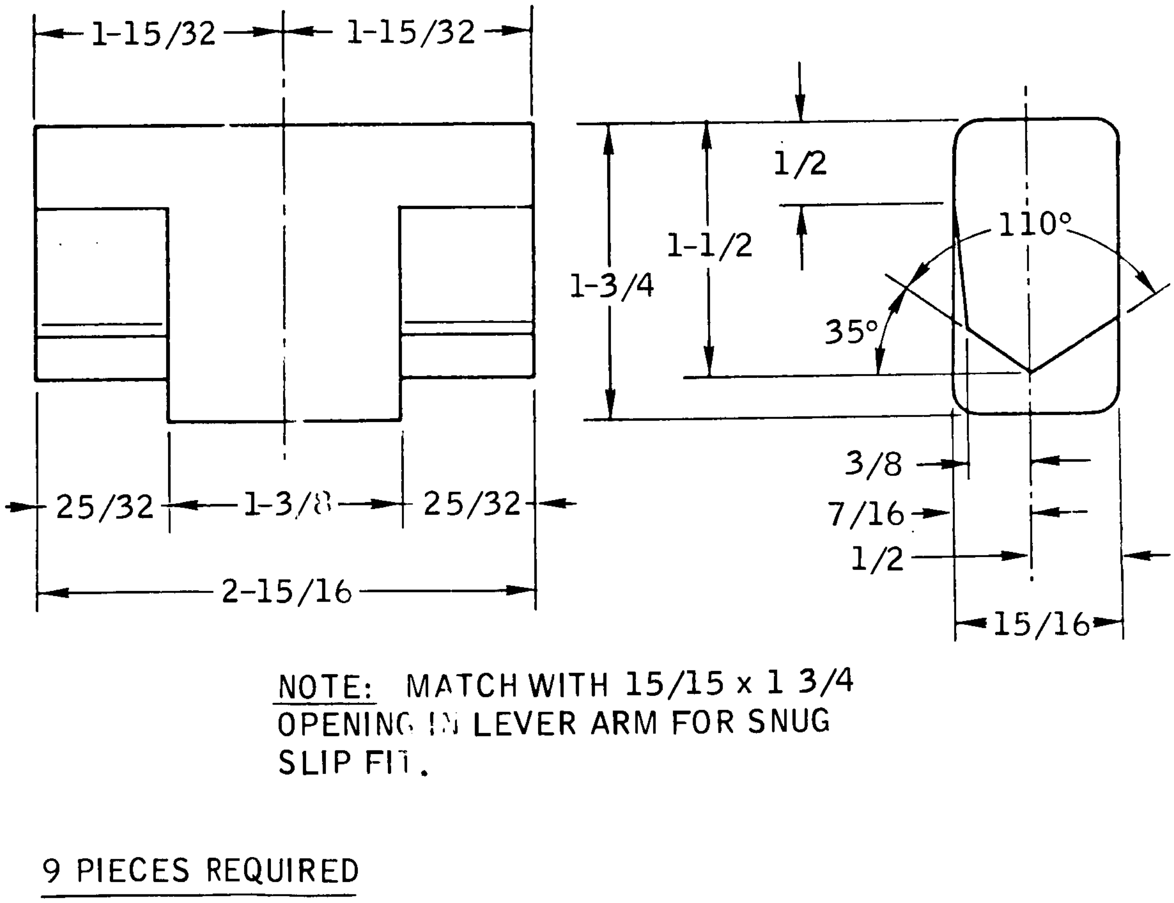


Figure 19. Lever Arm Fulcrum Knife Edge Pivot

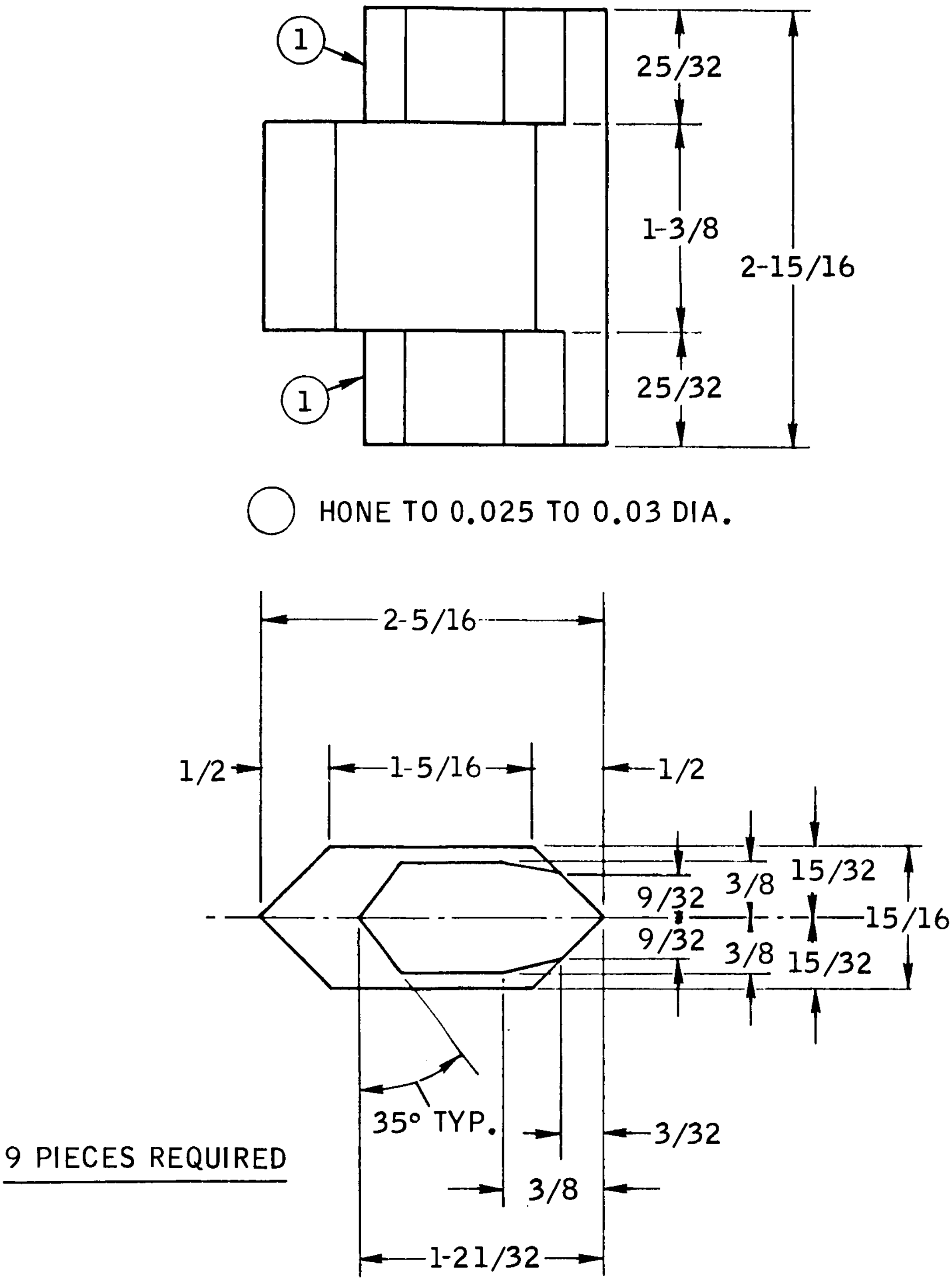


Figure 20. Pull Rod Knife Edge Pivot

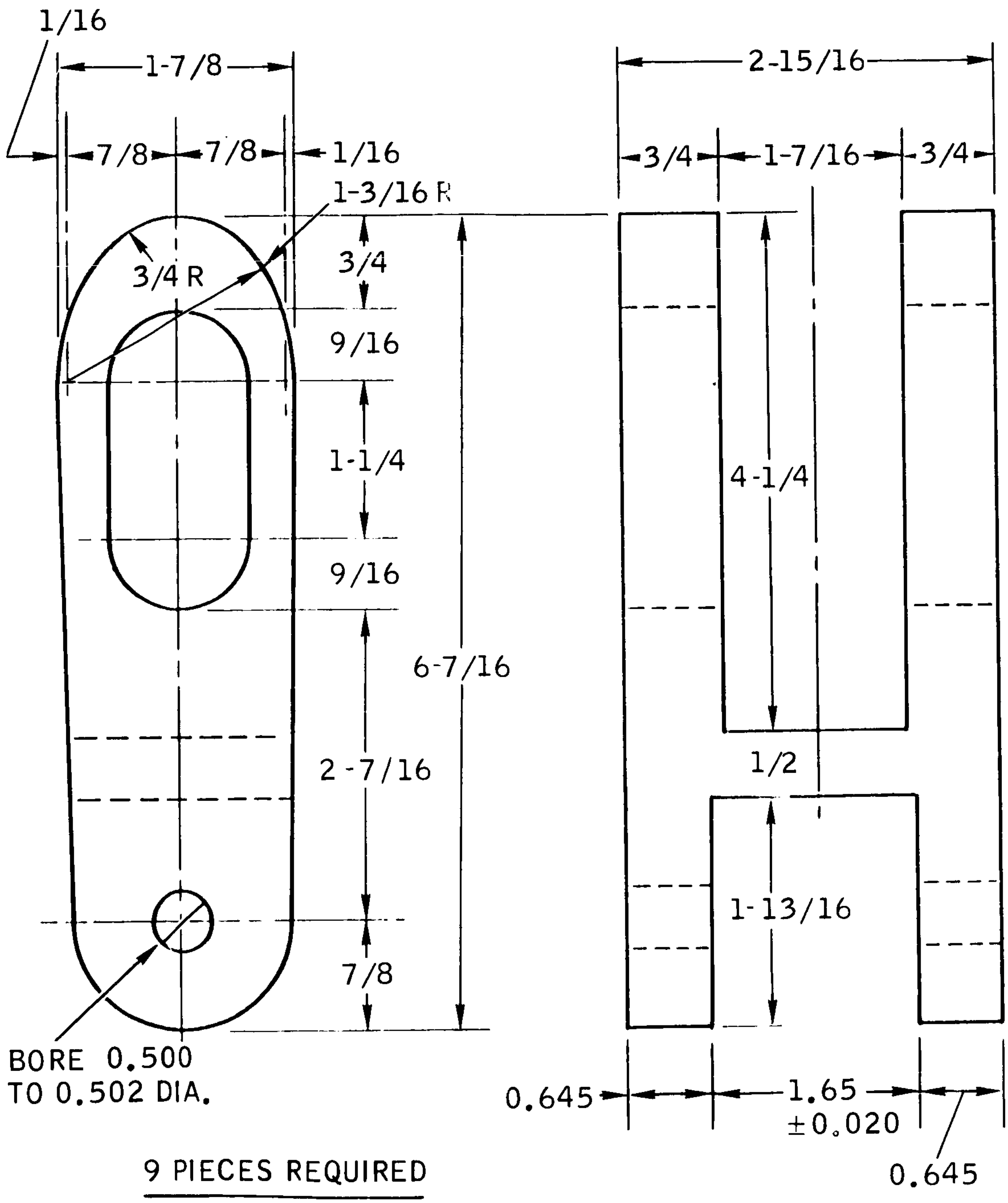
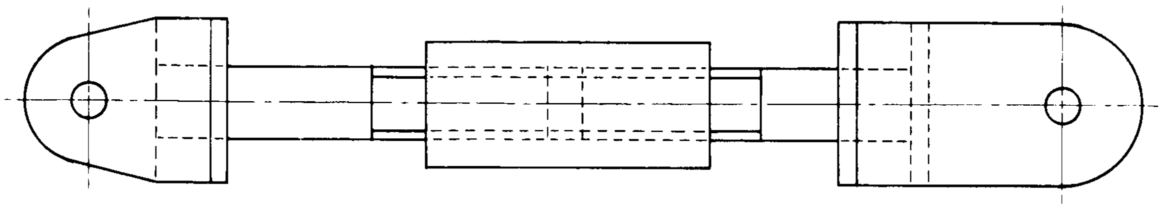
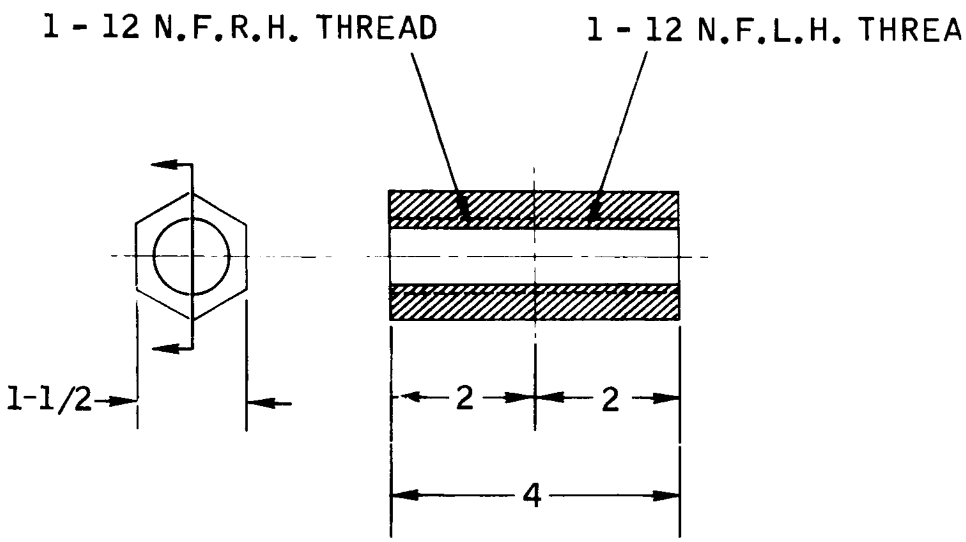


Figure 21. Pull Rod Attachment Link



9 PIECES REQUIRED

Figure 22. Turnbuckle Assembly



9 PIECES REQUIRED

Figure 23. Turnbuckle Barrel

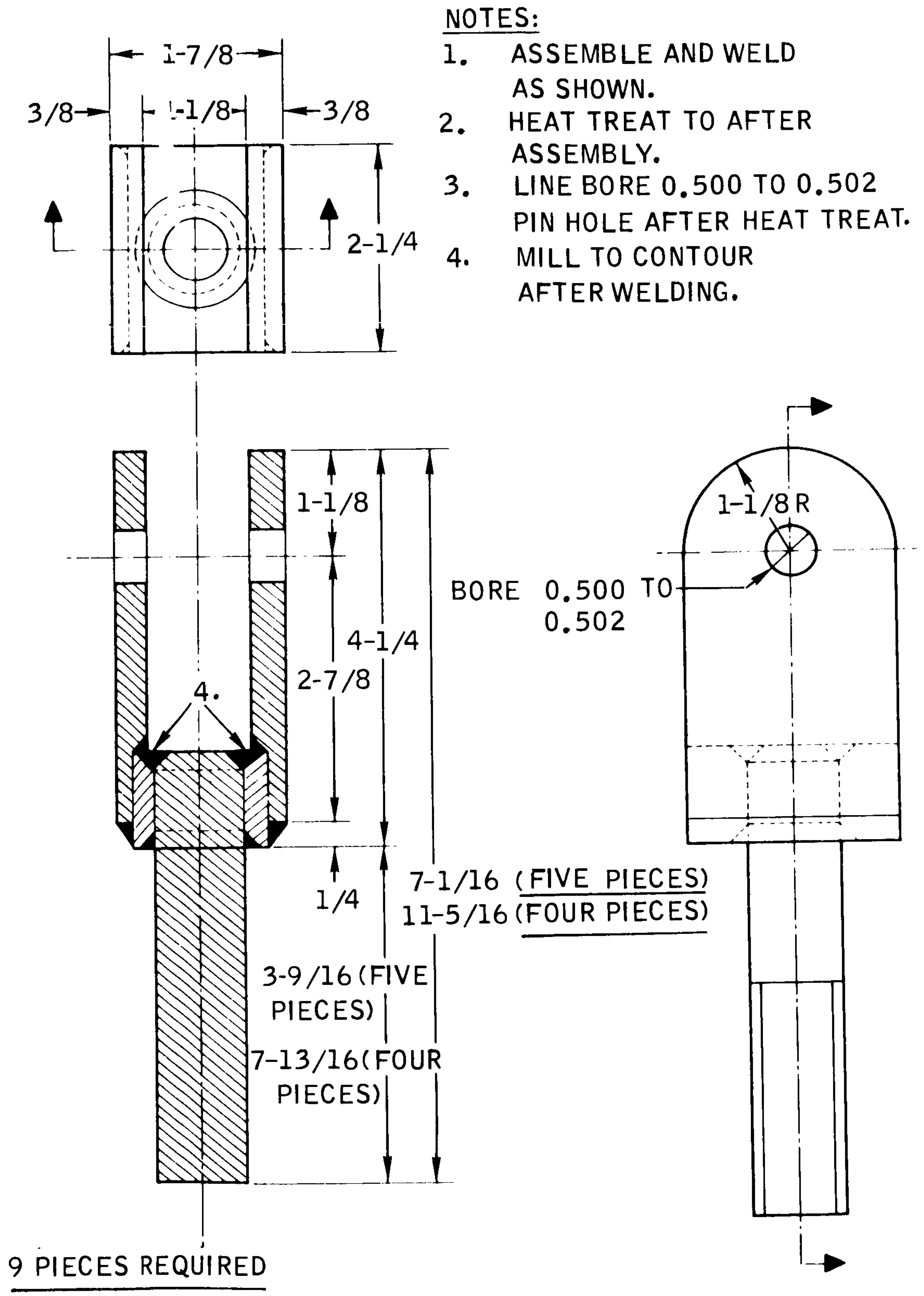


Figure 24. Chain Clevis Assembly

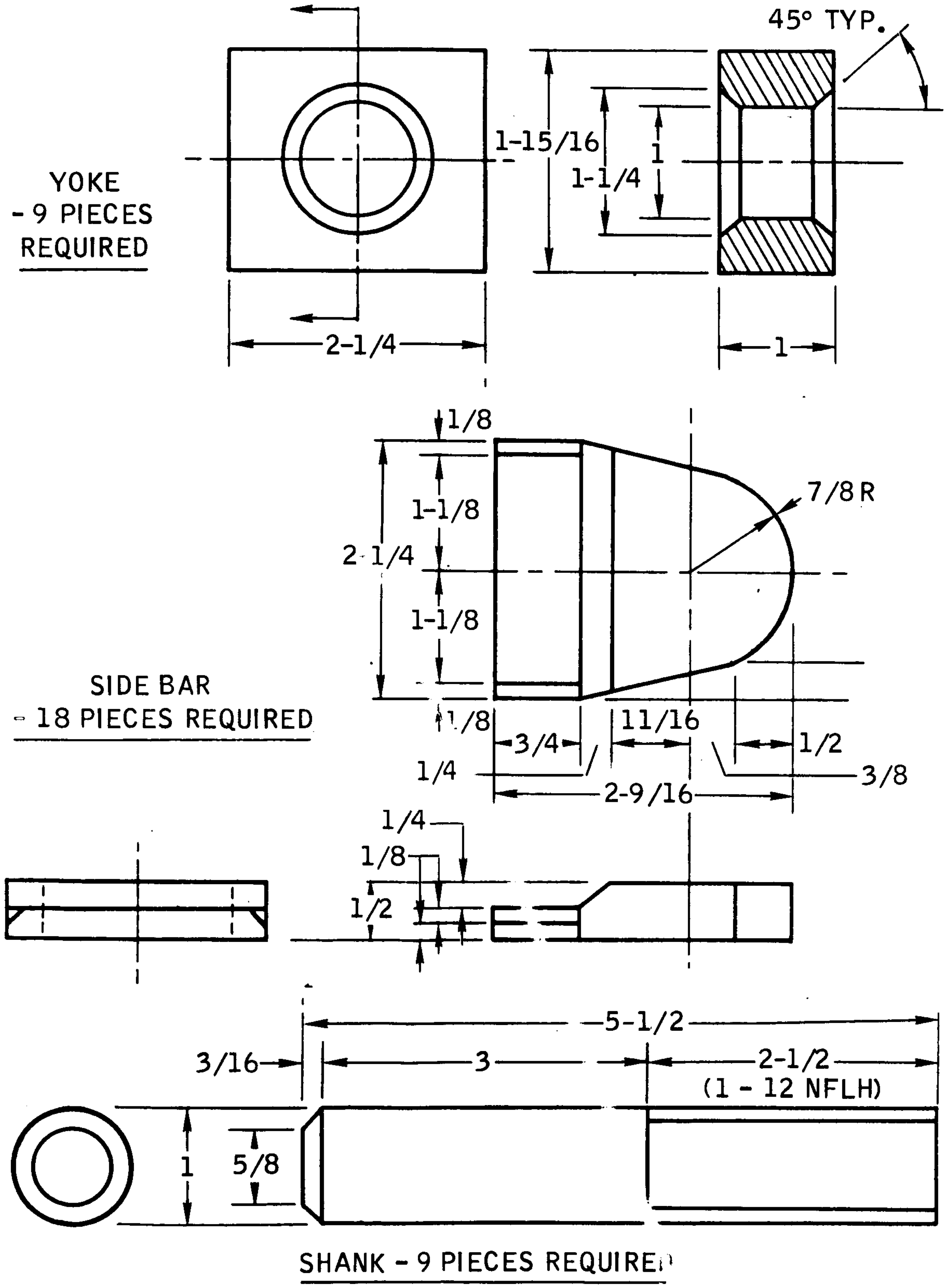


Figure 25. Chain Clevis Detail

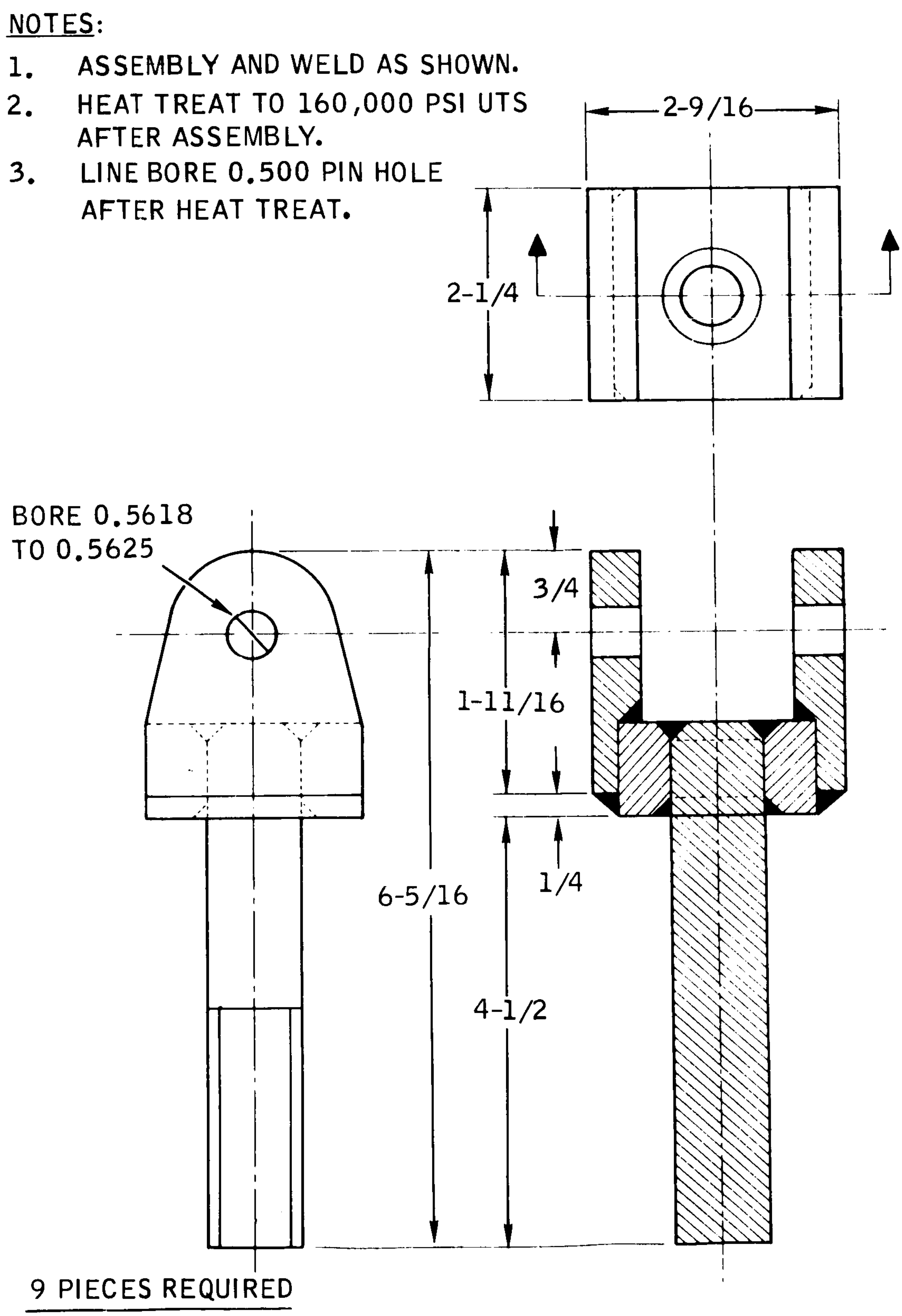


Figure 26. Bell Crank Clevis Assembly

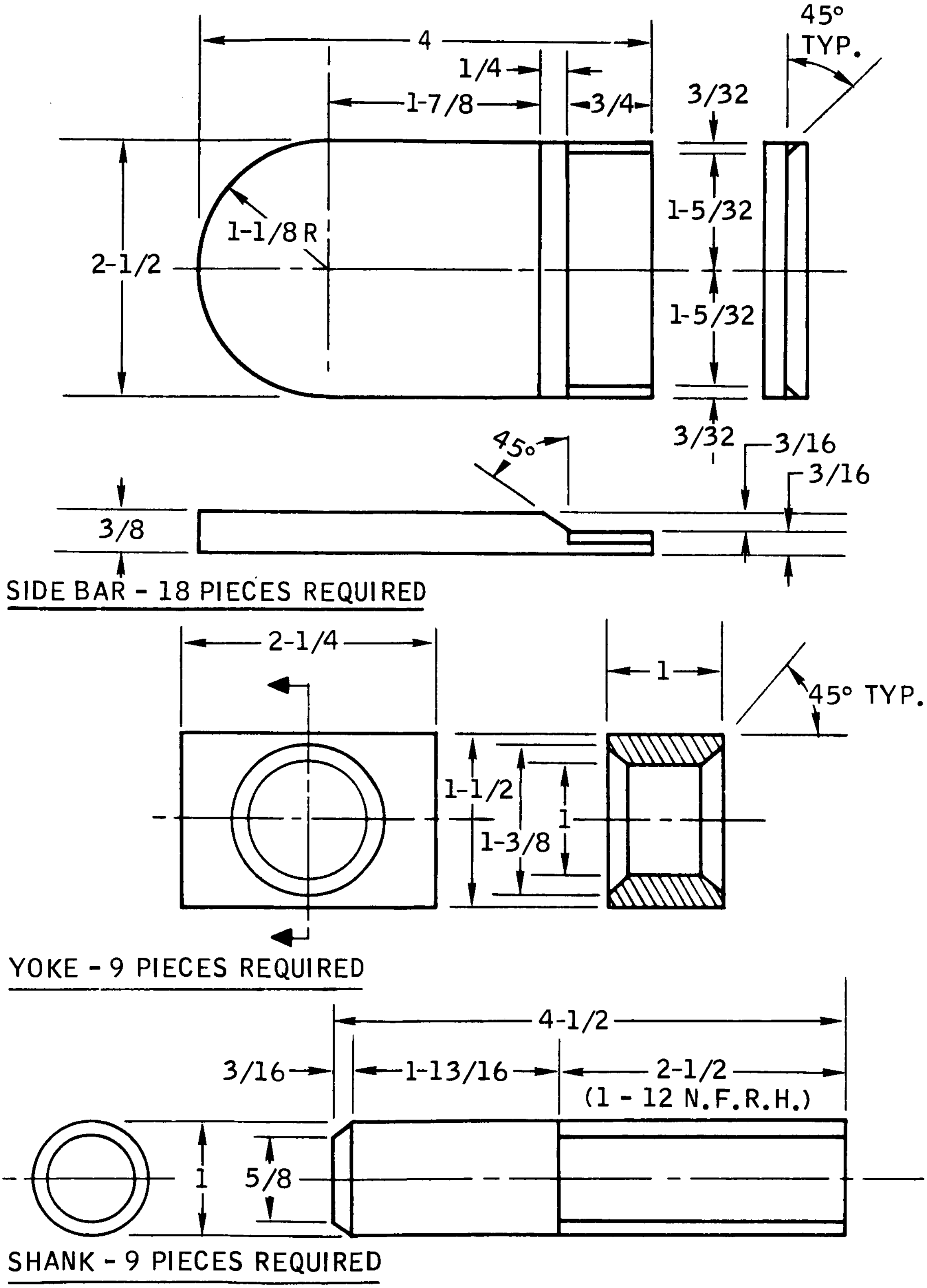


Figure 27. Bell Crank Clevis Details

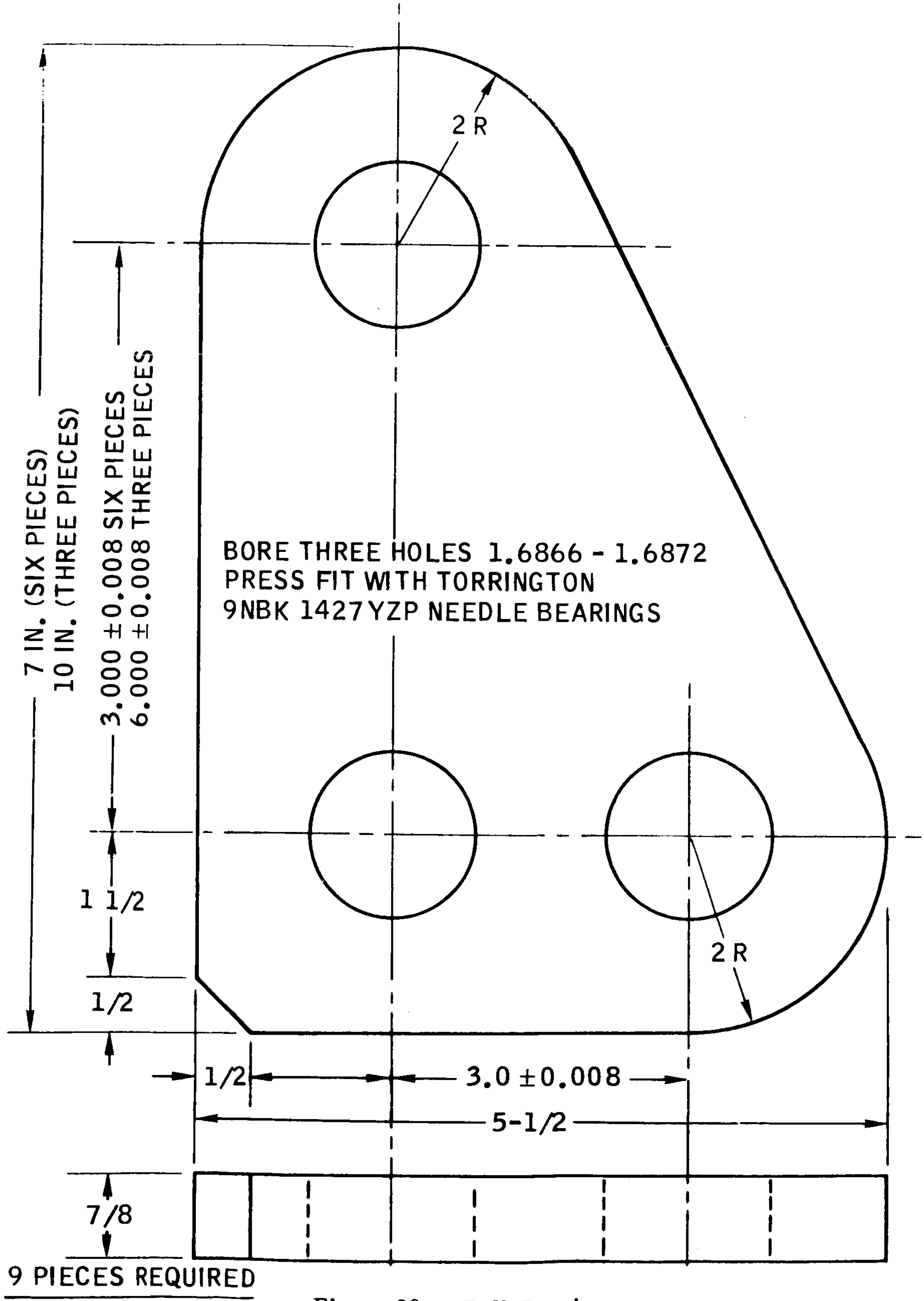
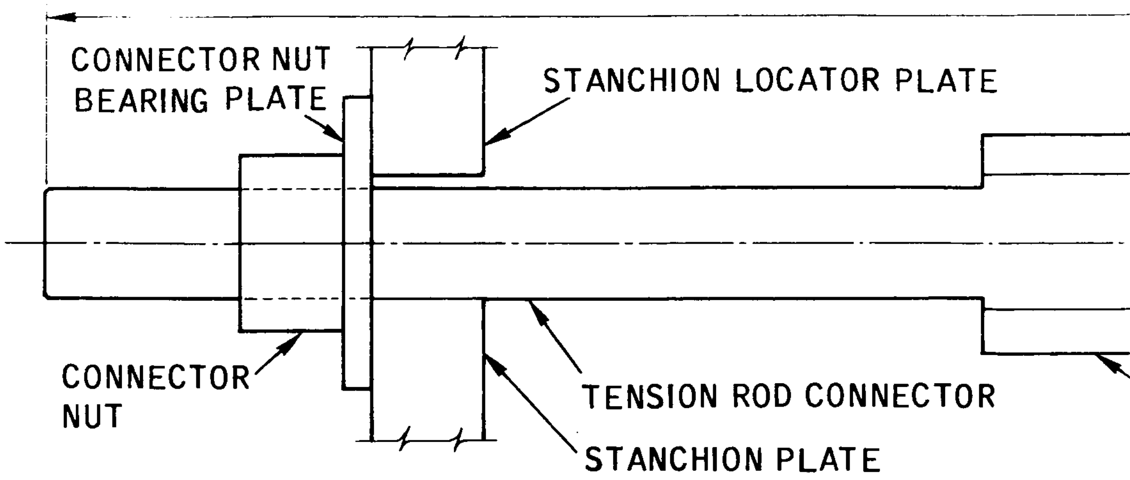
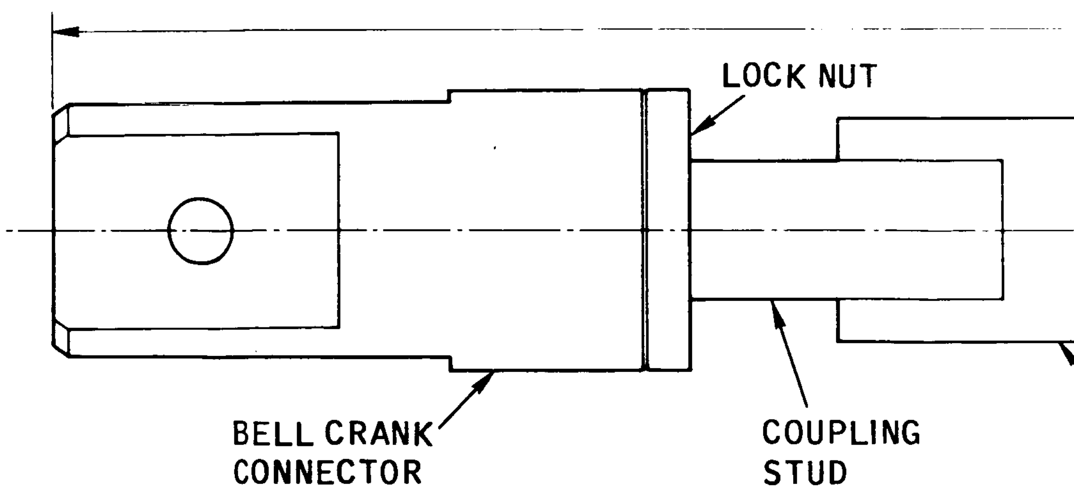


Figure 28. Bell Crank


CONNECTOR NUT
BEARING PLATE
STANCHION LOCATOR PLATE
CONNECTOR
NUT
TENSION ROD CONNECTOR
STANCHION PLATE


LOCK NUT
BELL CRANK
CONNECTOR
COUPLING
STUD

2

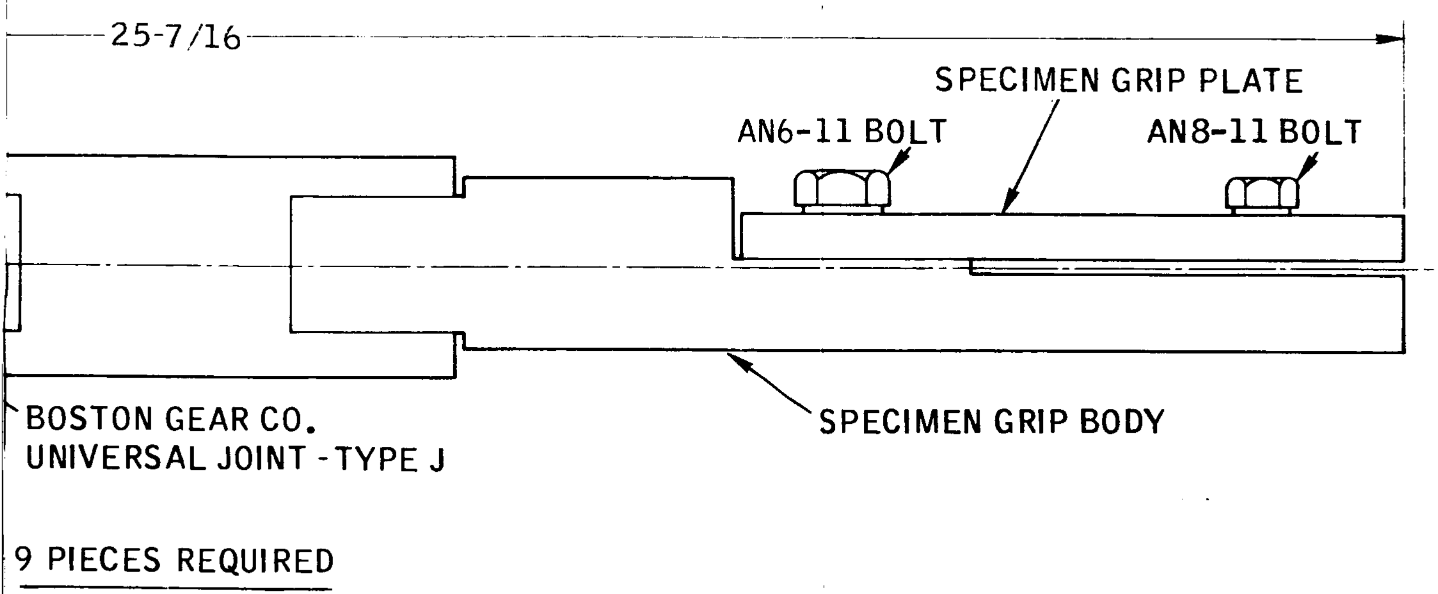


Figure 29. Specimen Grip Assembly - Stanchion Attachment (Schematic)

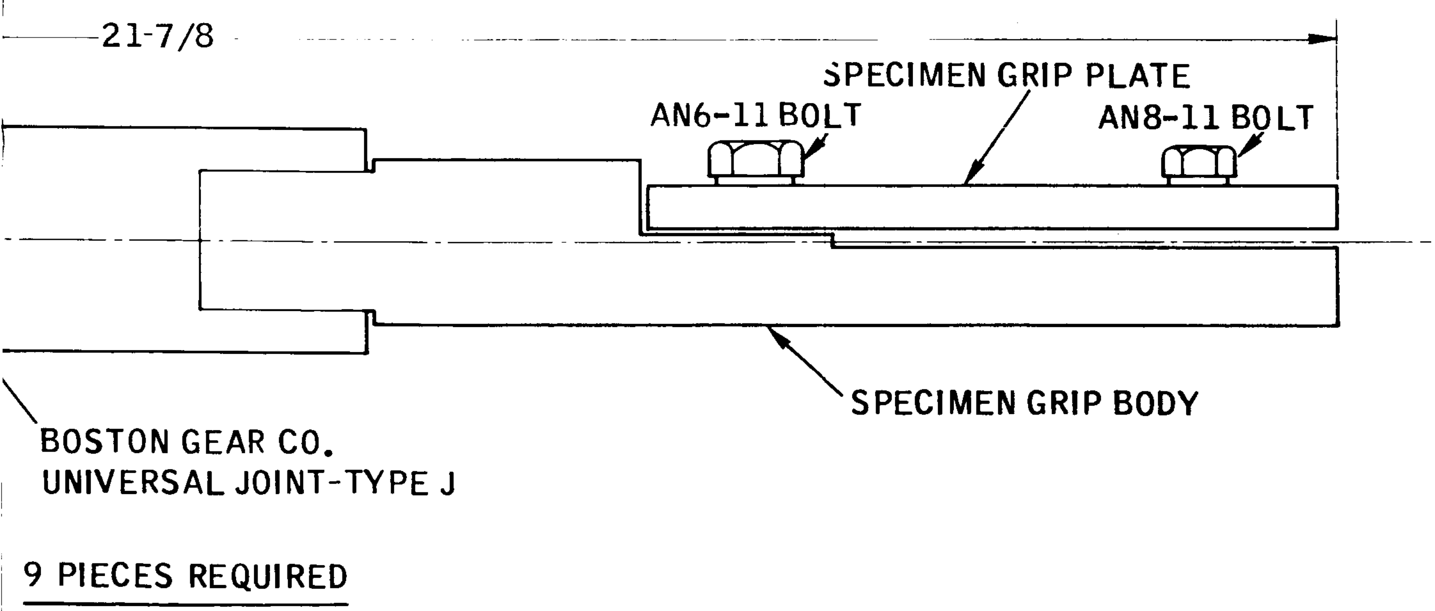


Figure 30. Specimen Grip Assembly - Bell Crank Attachment (Schematic)

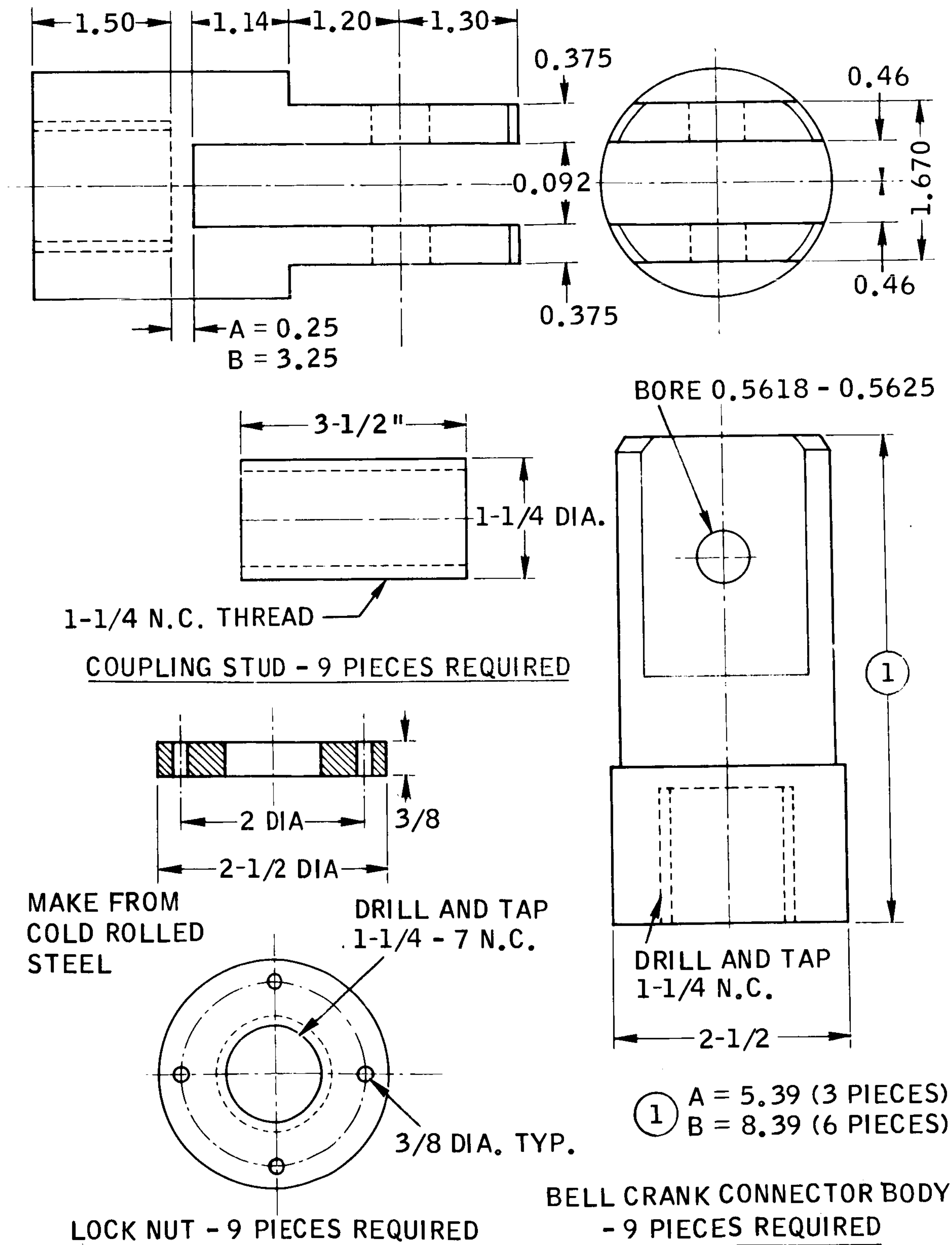
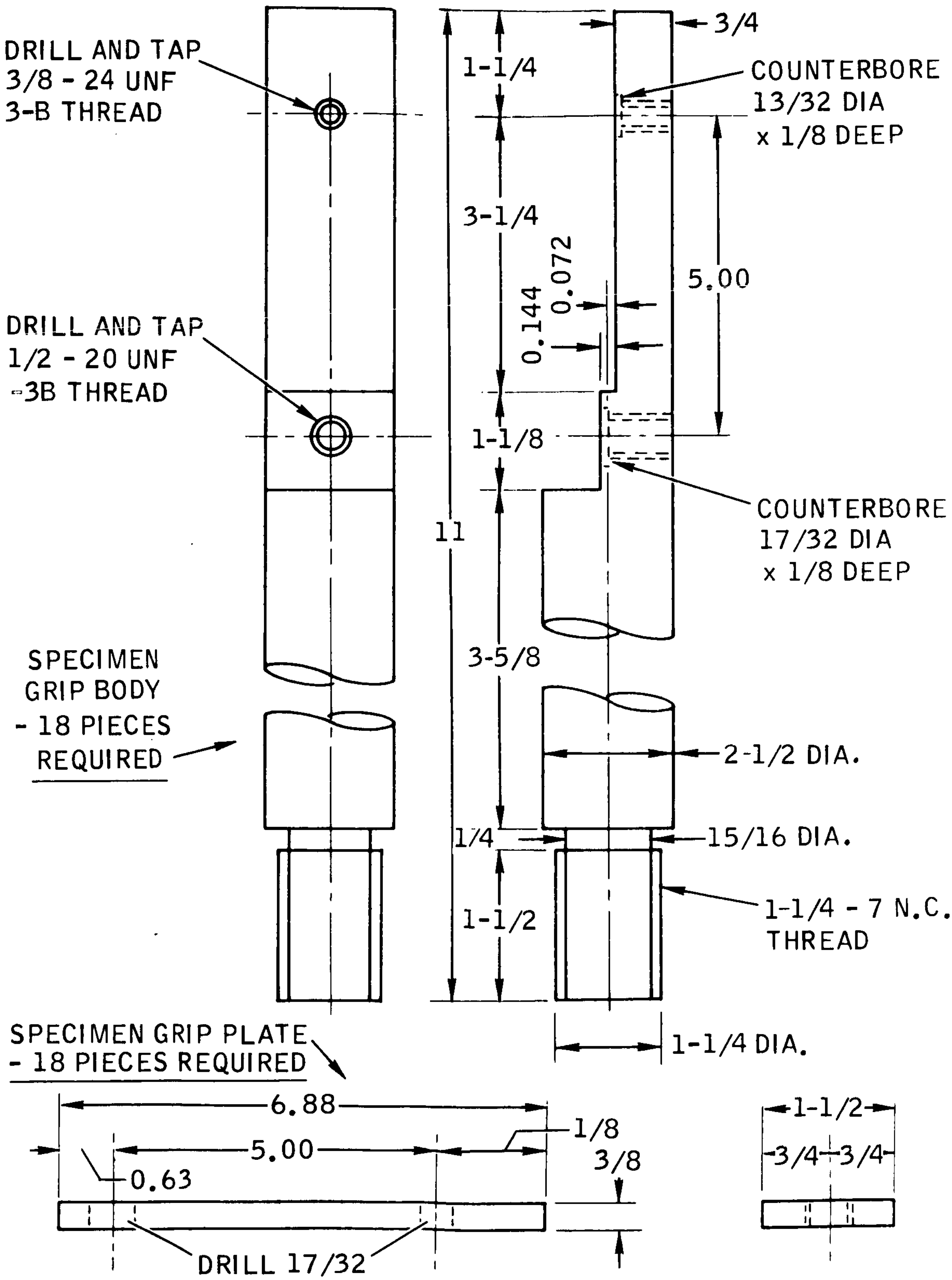


Figure 31. Bell Crank Connector Detail



1.13

3.62

Figure 32. Specimen Grip Details

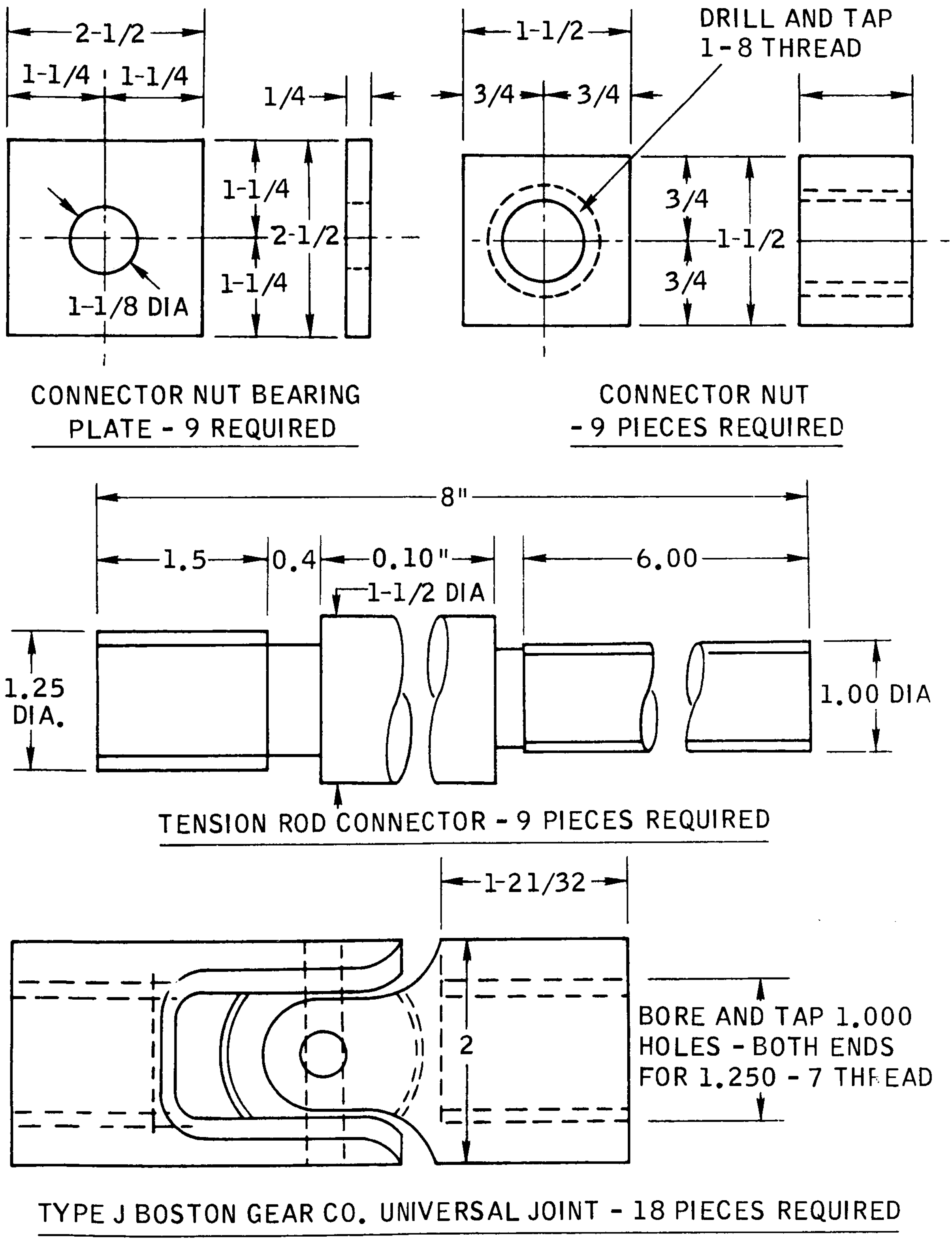


Figure 33 Specimen Grip Stanchion Attachment Detail

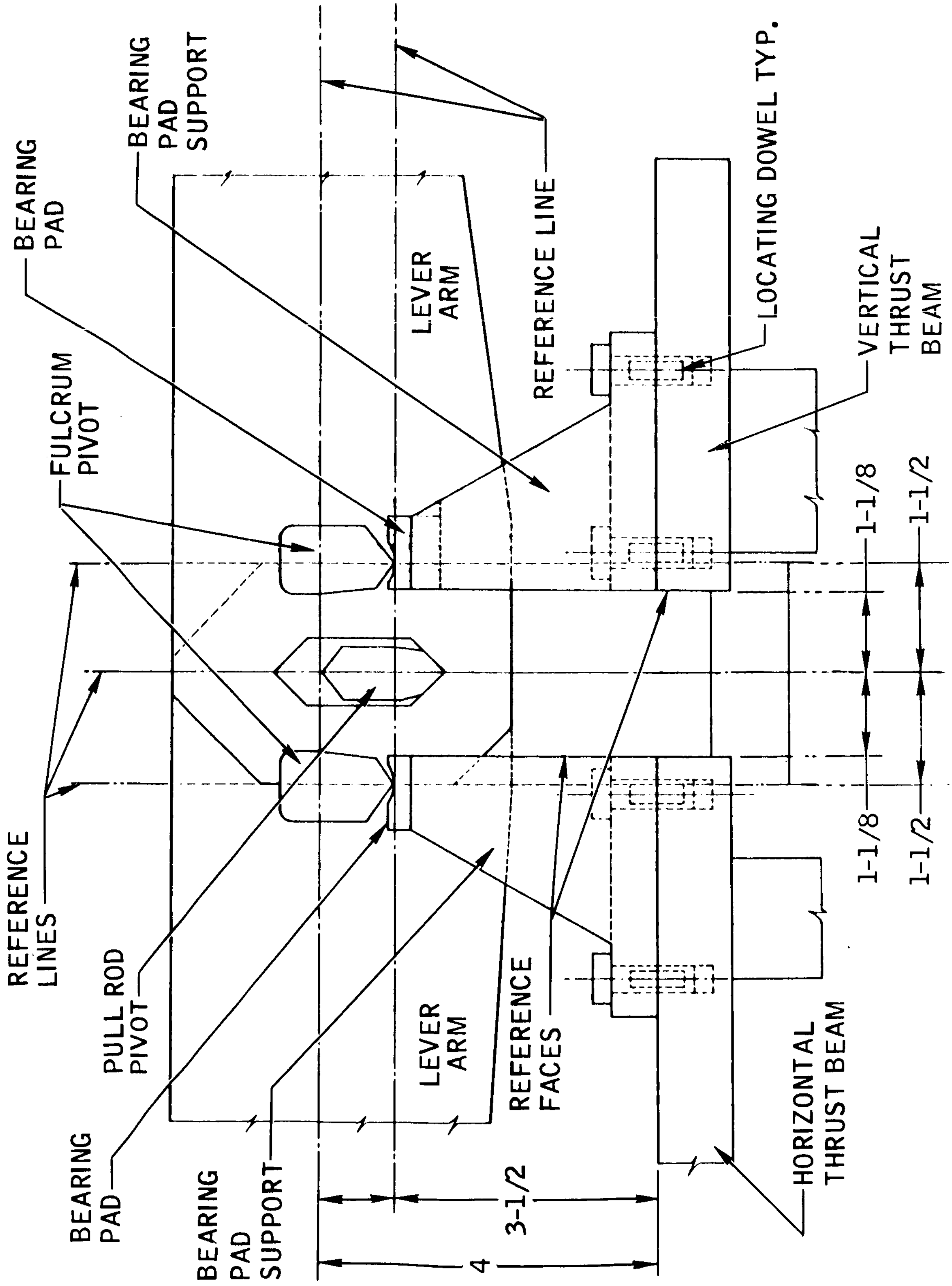


Figure 34. Lever Arm Support Assembly

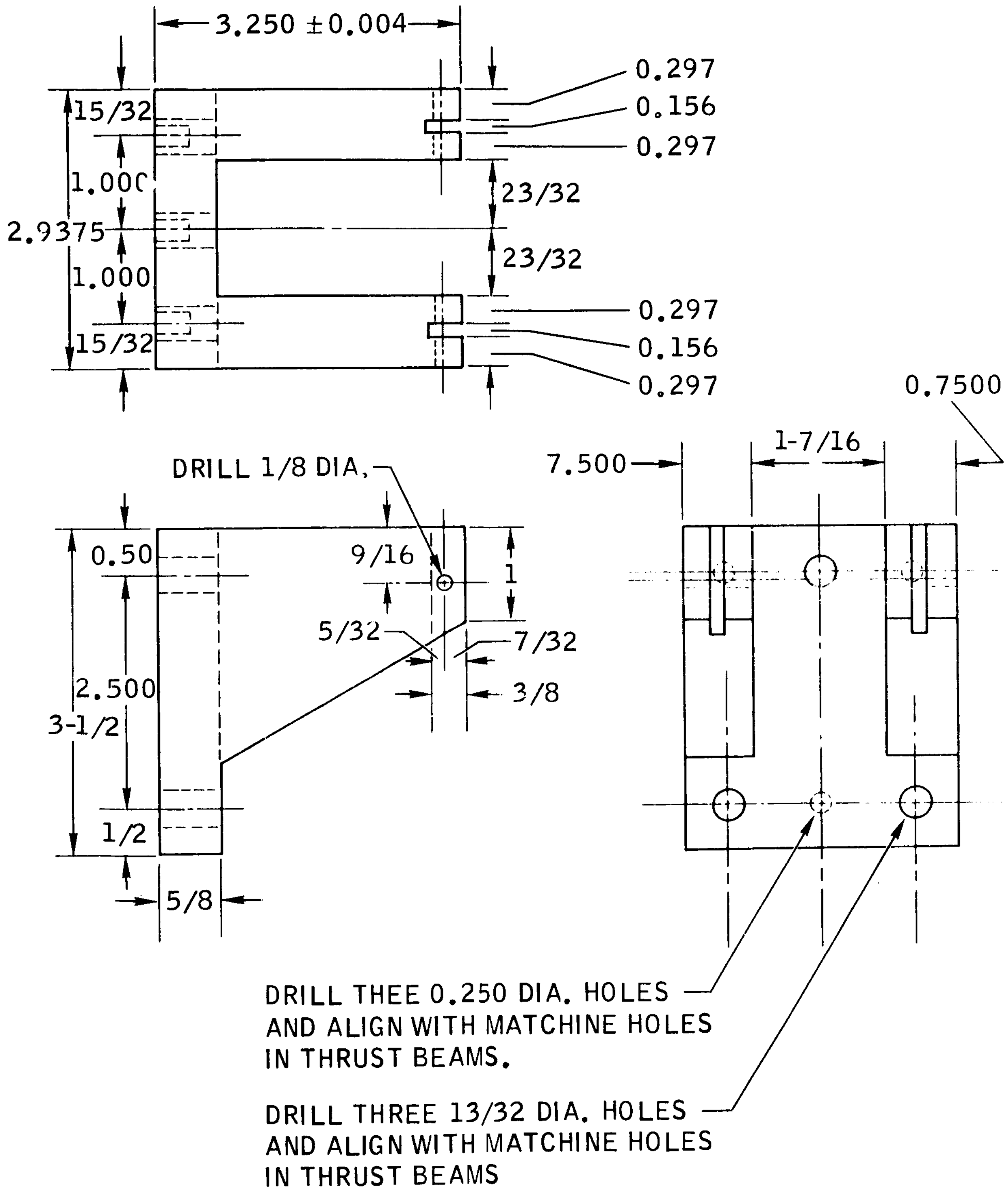
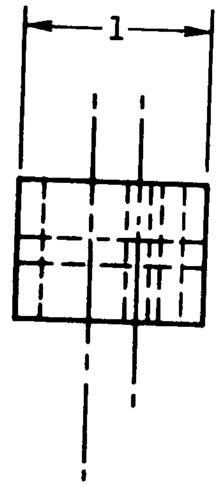
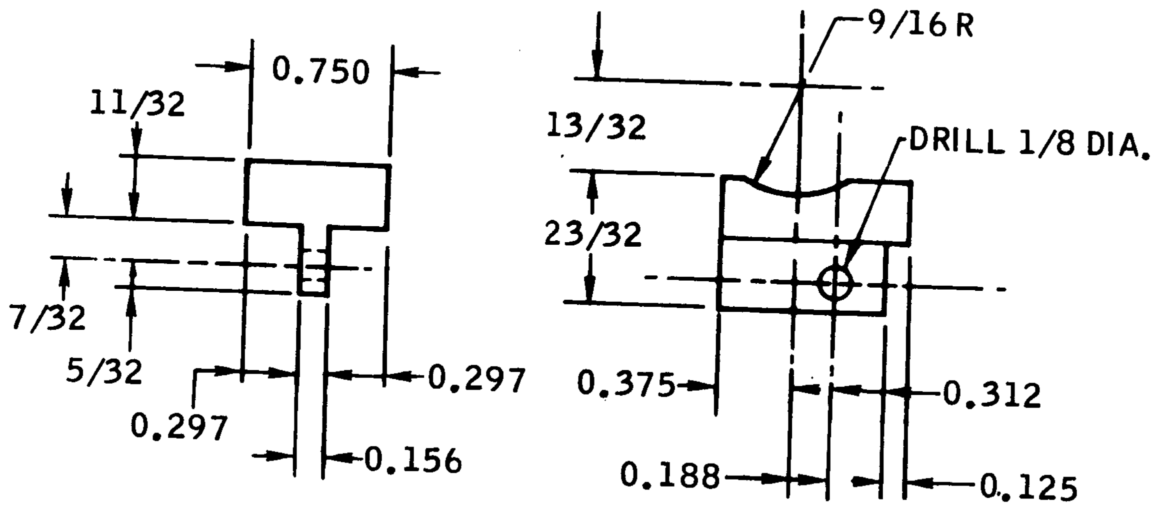


Figure 35. Lever Arm Bearing Pad Support

NOTE: *

MACHINE TO FIT SLOTS IN KNIFE EDGE BEARING PAD SUPPORT (FIGURE). DRILL 1/8 DIA MATCHINE HOLE AND PIN WITH 1/8 DIA x 1 DOWEL. FACE 3-1/2 x 3-1/2 SURFACE AND CUT 9/16 RADIUS HOLDING 3.500 DIMENSION (FIGURE). REMOVE PAD AFTER MACHINING, HEAT TREAT AND REINSTALL WITH PEENED 1/8 DIA x 1 DOWEL.

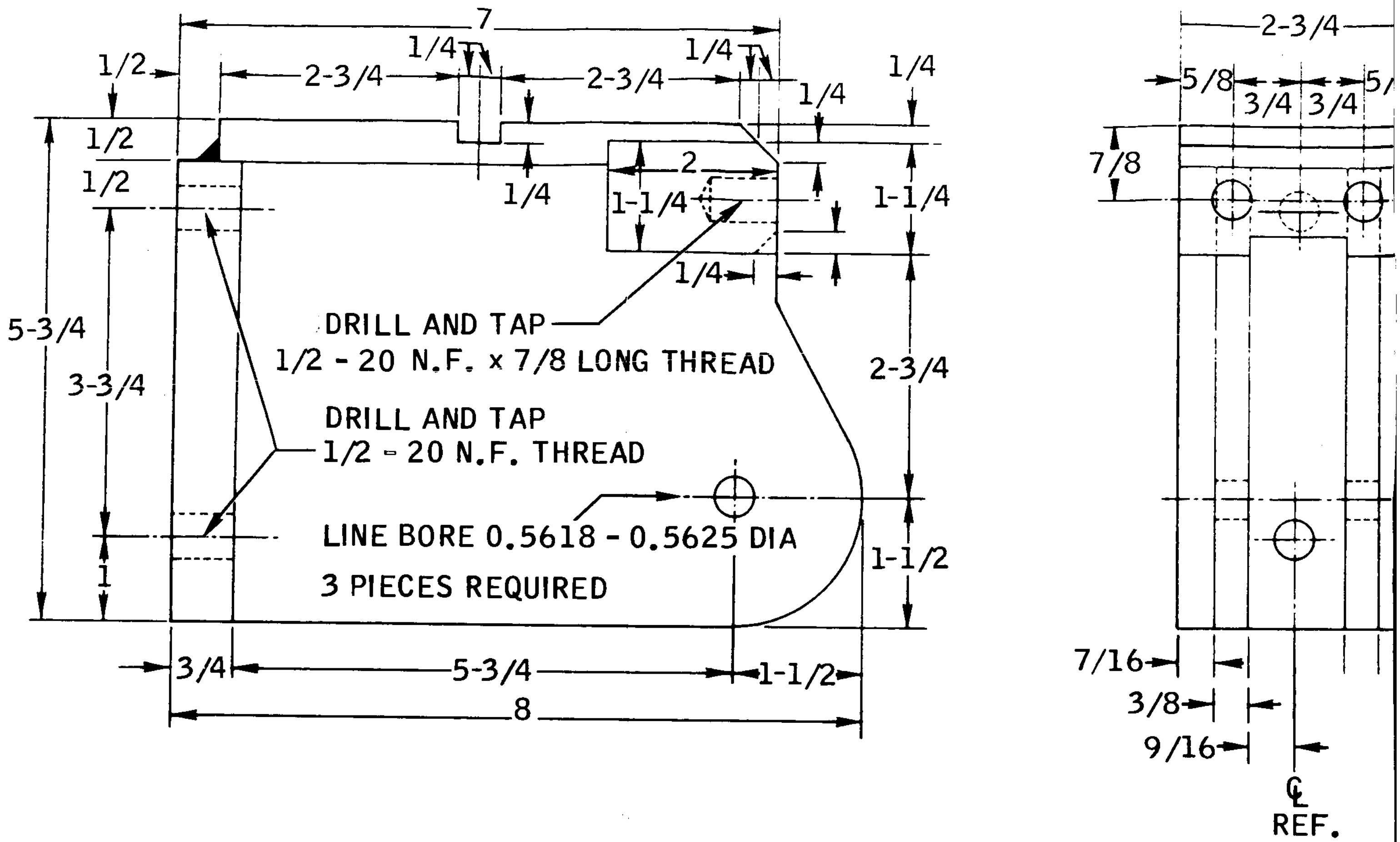




18 PIECES REQUIRED

Figure 36. Lever Arm Bearing Pad

*See also Page 37.



NOTES: 1. MAKE FROM 4130 STEEL.

2. ASSEMBLE WITH 1/4 IN. FILLET AND 1/4 IN. GROOVED WELDS AS REQUIRED FOR FULL WELD CONNECTION AT ALL JOINTS.

3. HEAT TREAT TO 160,000 PSI UTS AFTER WELDING

4. FIT 1/4 x 1/2 KEY WAY FOR SNUG SLIDING FIT ON 1/2 x 1/2 KEY IN HORIZONTAL THRUST BEAM.

5. FACE AND SQUARE 2-3/4 x 5-3/4 AND 2-3/4 x 7 FACES FOR SNUG FIT WITH HORIZONTAL THRUST BEAM.

6. LOCATE WITH RESPECT TO REFERENCES AND DRILL AND TAP AS REQUIRED TO PRESERVE LOCATIONS.

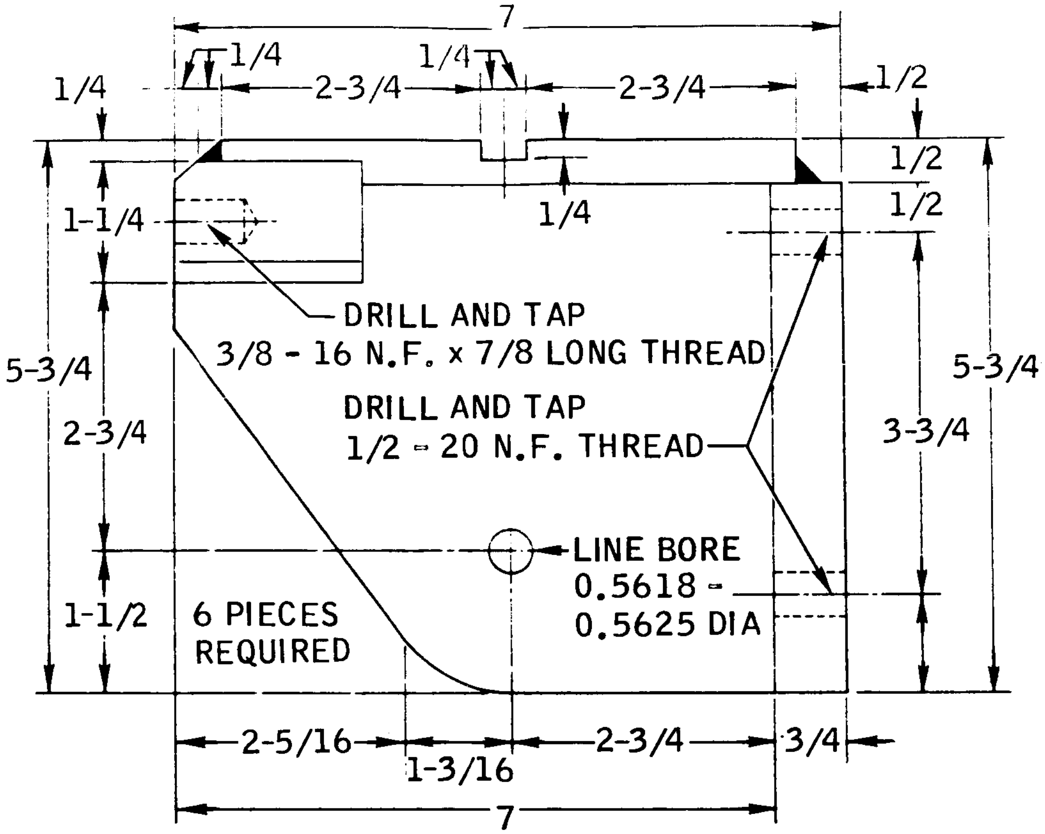


Figure 37. Bell Crank Supports

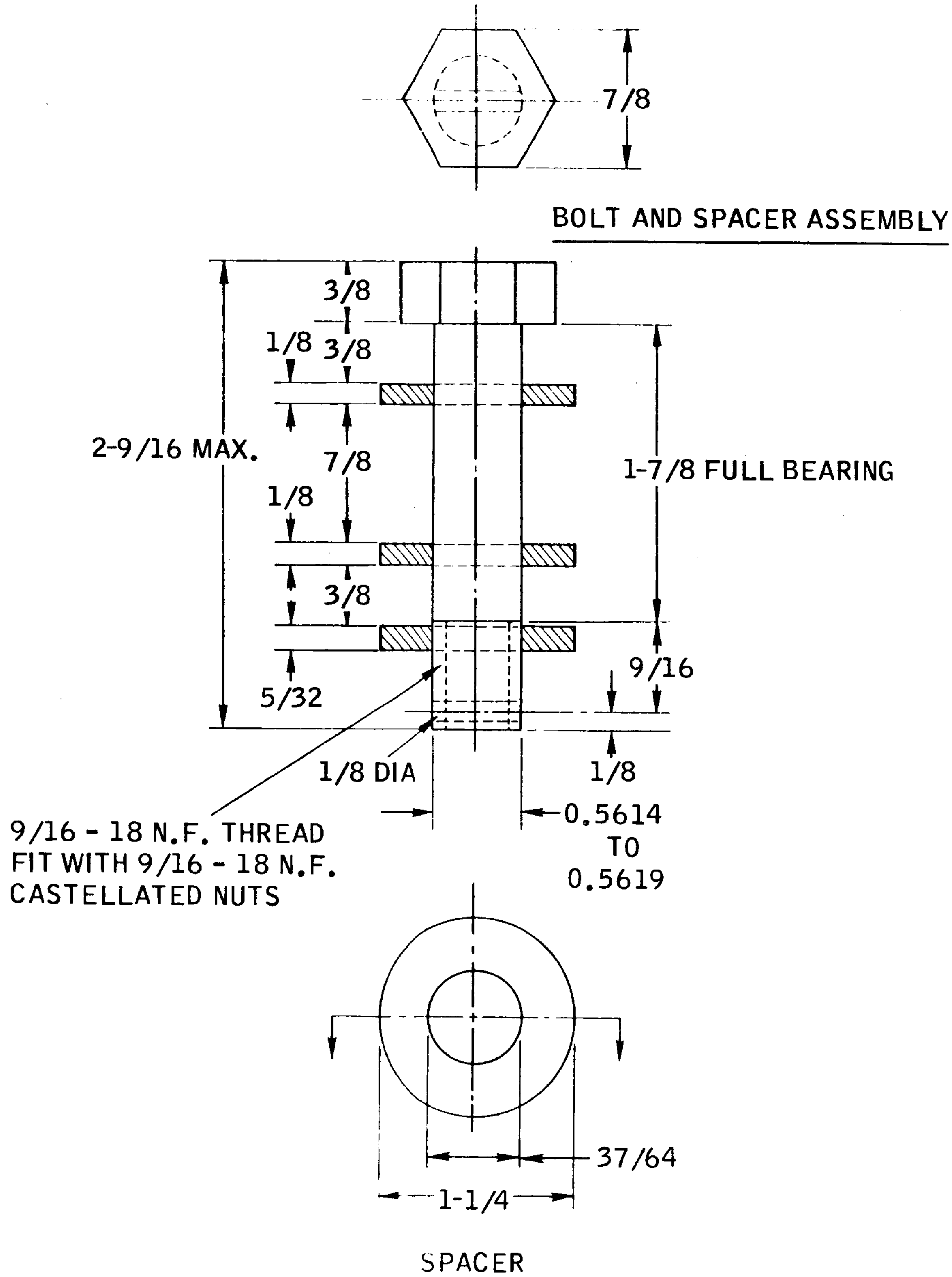


Figure 38. Bell Crank Pivot Assembly

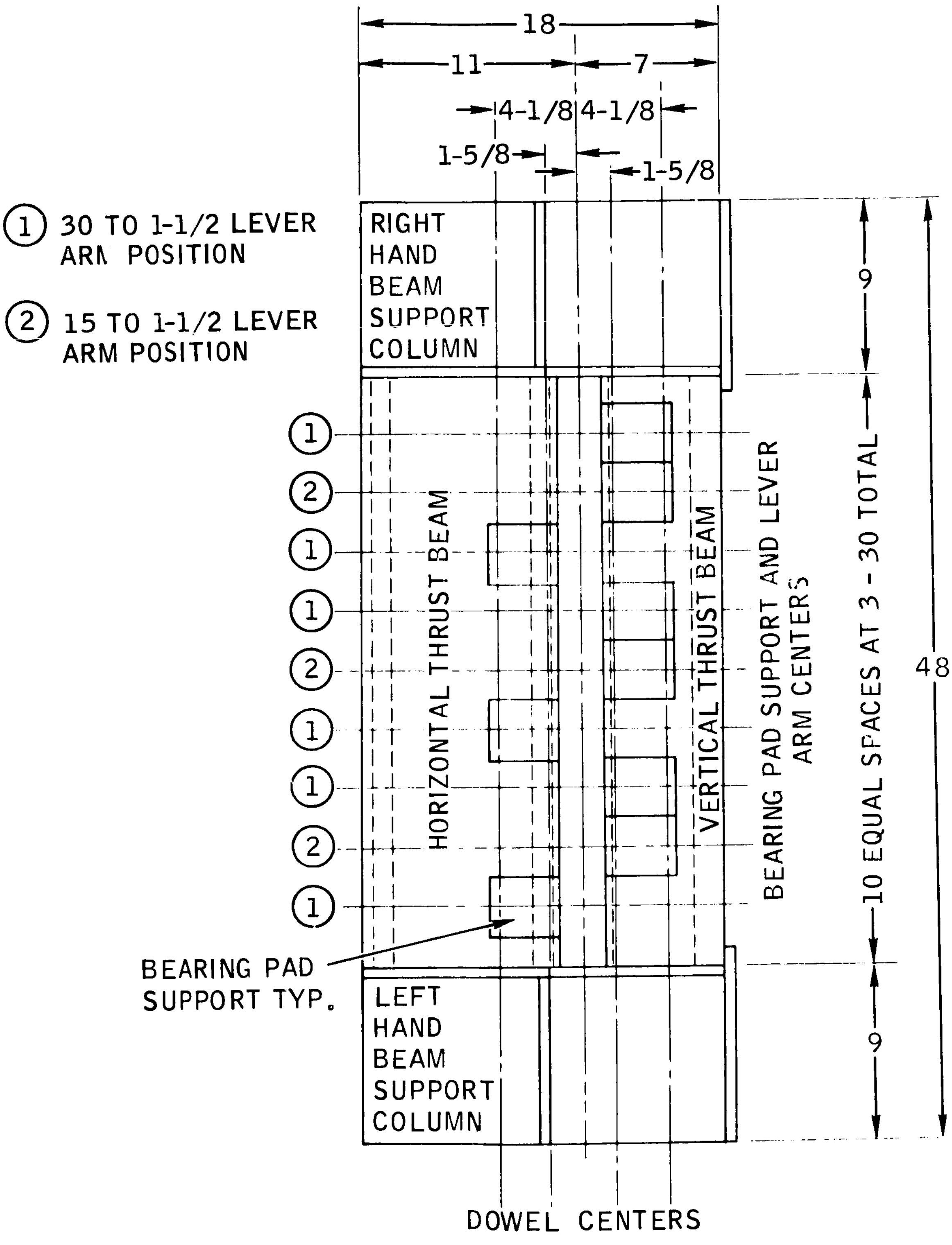
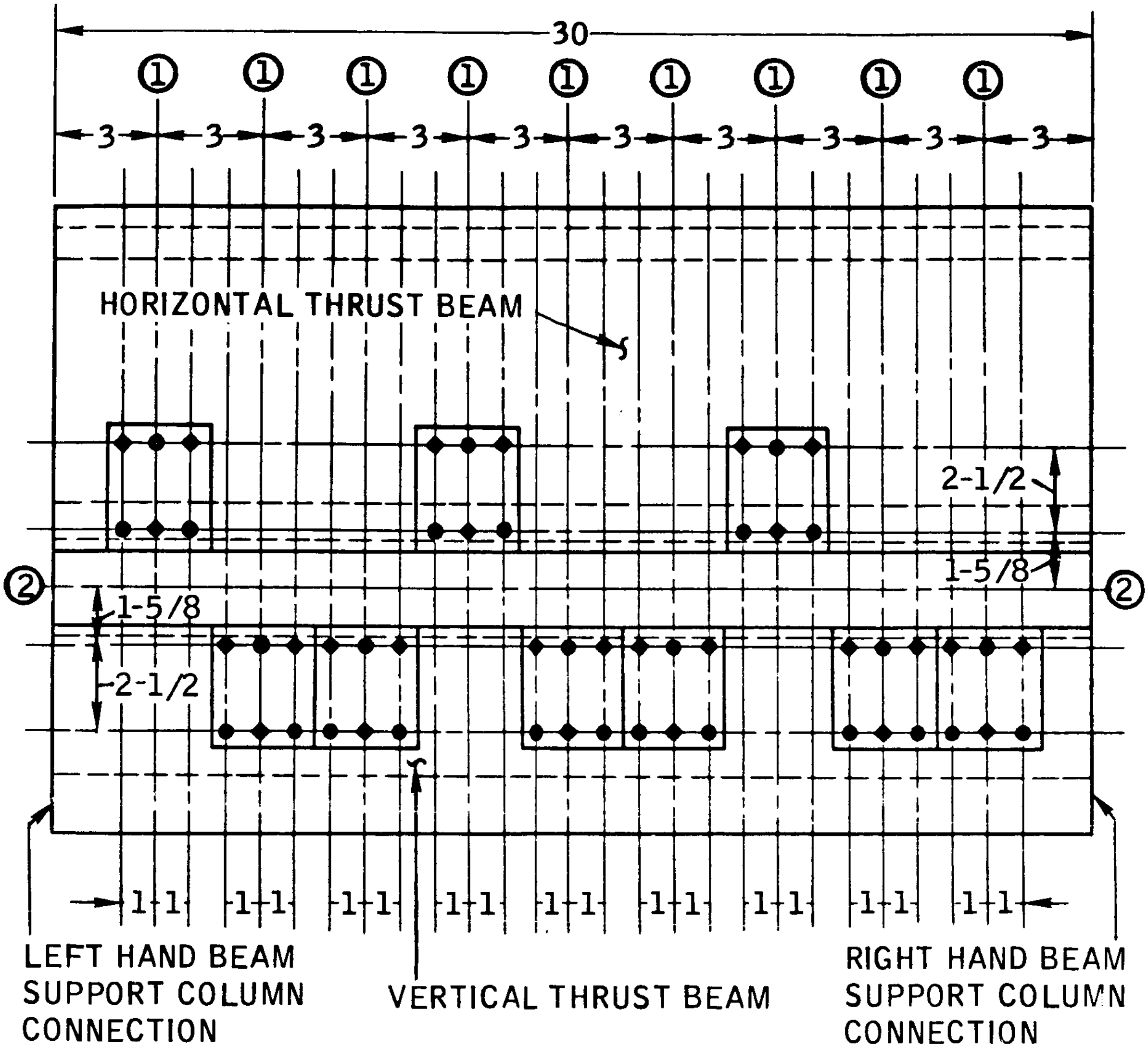


Figure 39. Lever Arm Support Arrangement At Top Of Loading Column



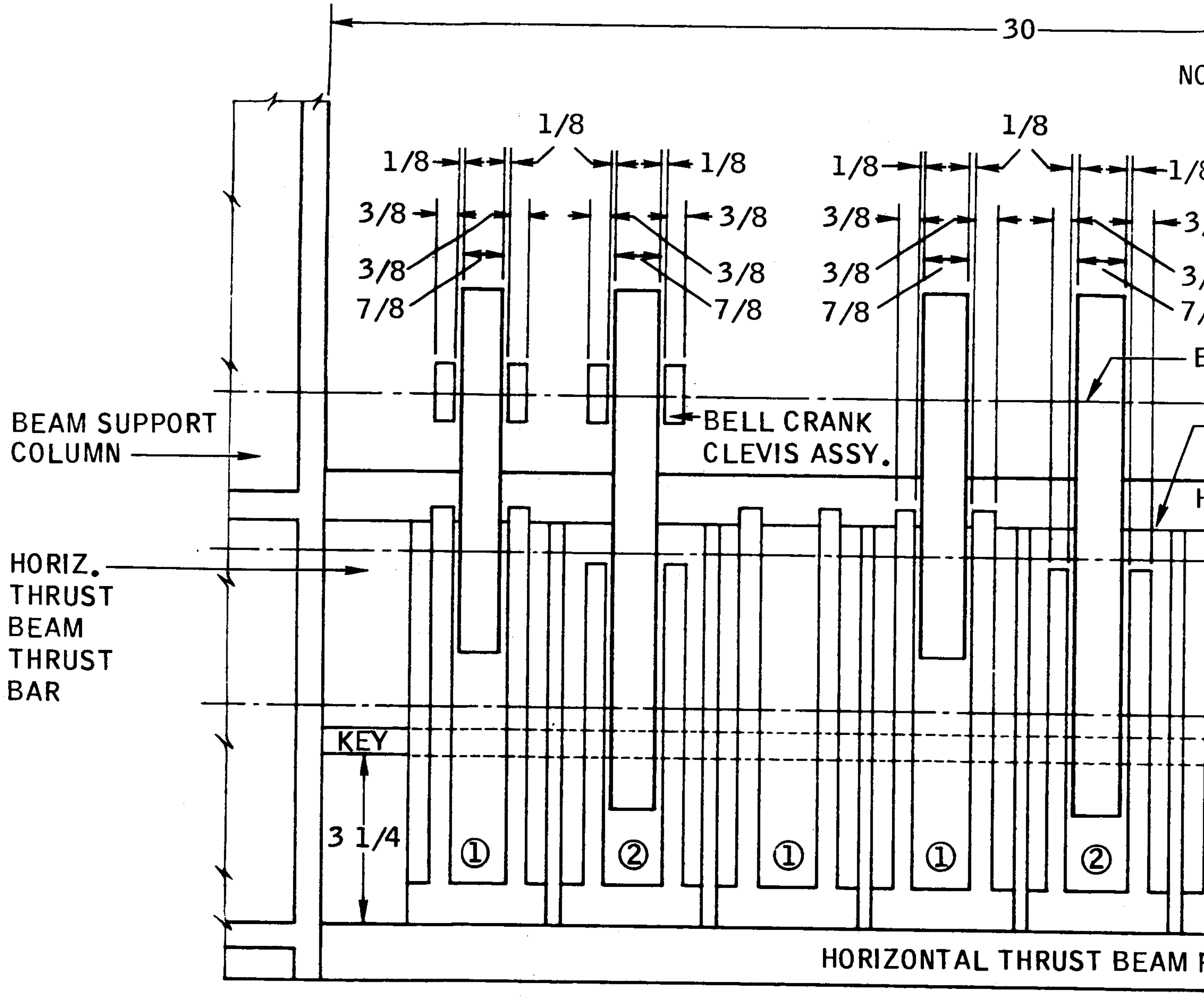
① COMMON CENTERLINE REFERENCE FOR THRUST BEAM, LEVER ARM, LEVER ARM PIVOTS, LEVER ARM BEARING PAD, AND BEARING PAD SUPPORT LOCATION.

② COMMON REFERENCE PLANE FOR THRUST BEAM AND BEARING PAD SUPPORT LOCATION. REFER TO FIGURE 34.

● 1/4 DIA. x 1/2 DEEP DOWEL. HOLES IN THRUST BEAMS AND BEARING SUPPORT PADS MATCHED. FIT WITH 1/4 DIA. x 1 DOWELS, LIGHT PRESS FIT.

◆ TAPPED HOLES IN THRUST BEAMS FOR 3/8 - 24 x 3/4 MIN THREAD. DRILLED 3/8 THROUGH HOLES IN BEARING PAD SUPPORTS.

Figure 40. Hole Pattern For Thrust Beam Top Surfaces



30
NO
1/8
1/8
1/8
3/8
3/8
3/8
3/8
7/8
7/8
BEAM SUPPORT COLUMN
BELL CRANK CLEVIS ASSY.
HORIZ. THRUST BEAM THRUST BAR
KEY
3 1/4
①
②
HORIZONTAL THRUST BEAM

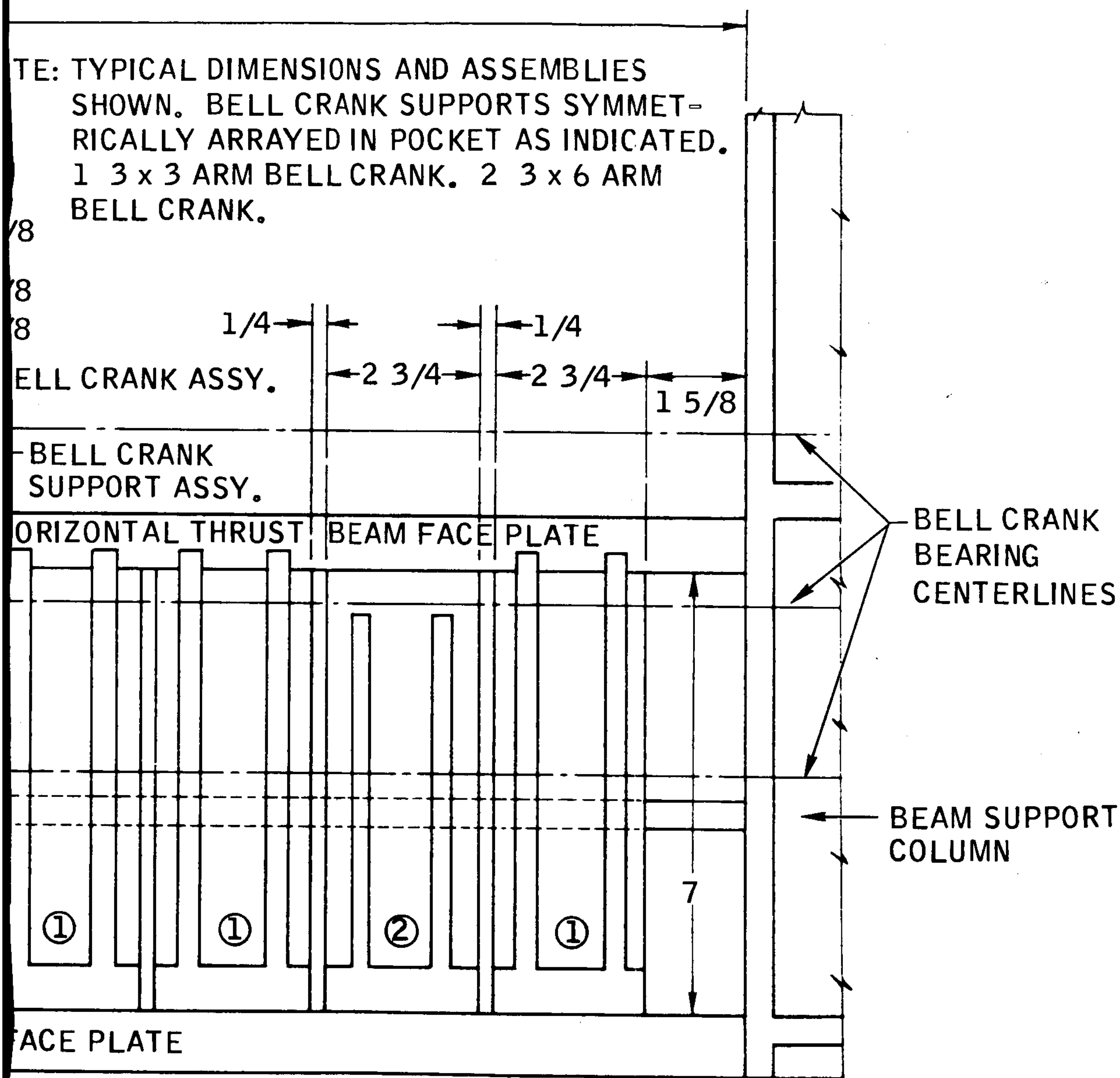
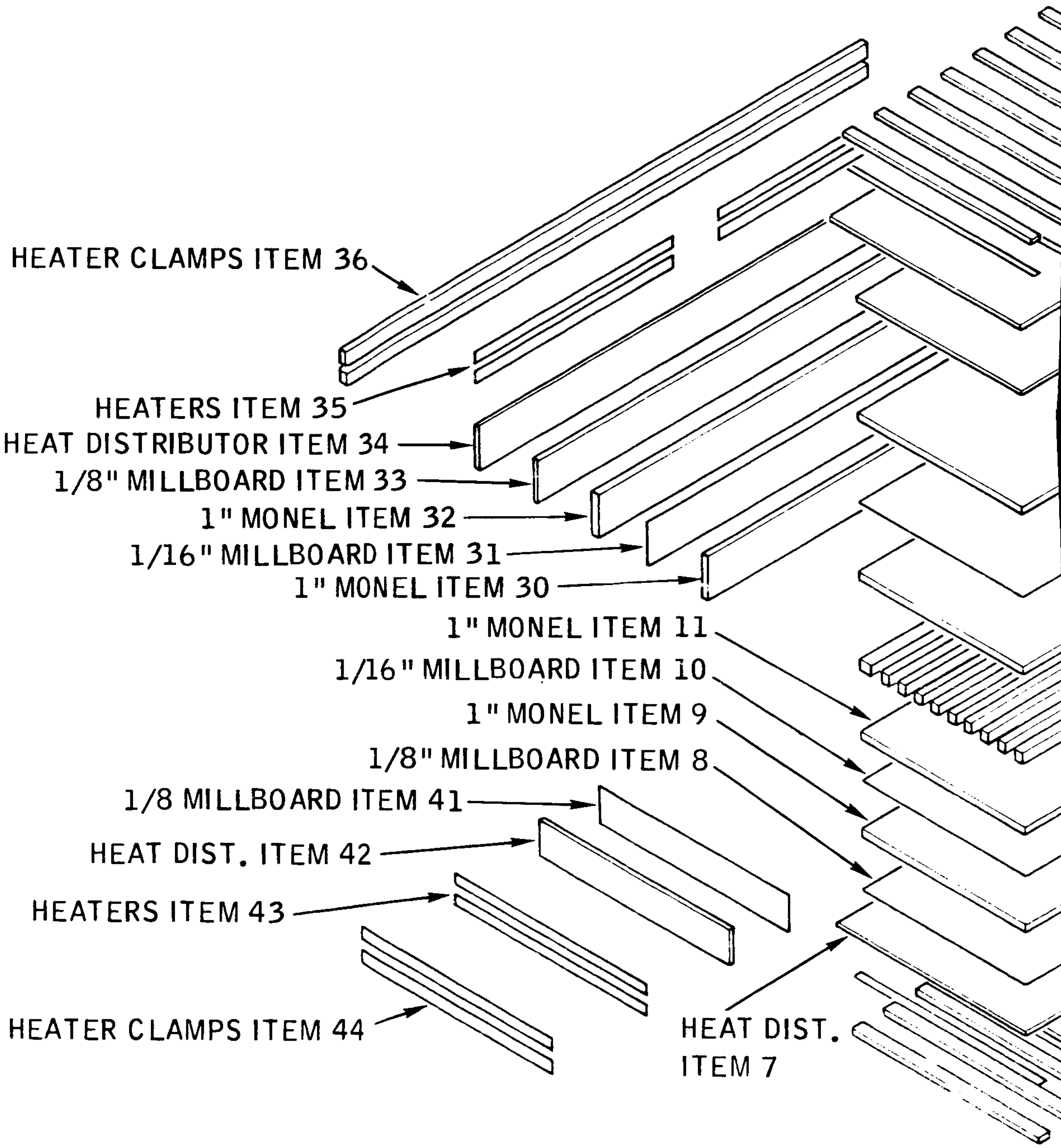


Figure 41. Bell Crank Assembly Installation

F1


HEATER CLAMPS ITEM 36
HEATERS ITEM 35
HEAT DISTRIBUTOR ITEM 34
1/8" MILLBOARD ITEM 33
1" MONEL ITEM 32
1/16" MILLBOARD ITEM 31
1" MONEL ITEM 30
1" MONEL ITEM 11
1/16" MILLBOARD ITEM 10
1" MONEL ITEM 9
1/8" MILLBOARD ITEM 8
1/8 MILLBOARD ITEM 41
HEAT DIST. ITEM 42
HEATERS ITEM 43
HEATER CLAMPS ITEM 44
HEAT DIST. ITEM 7

F2

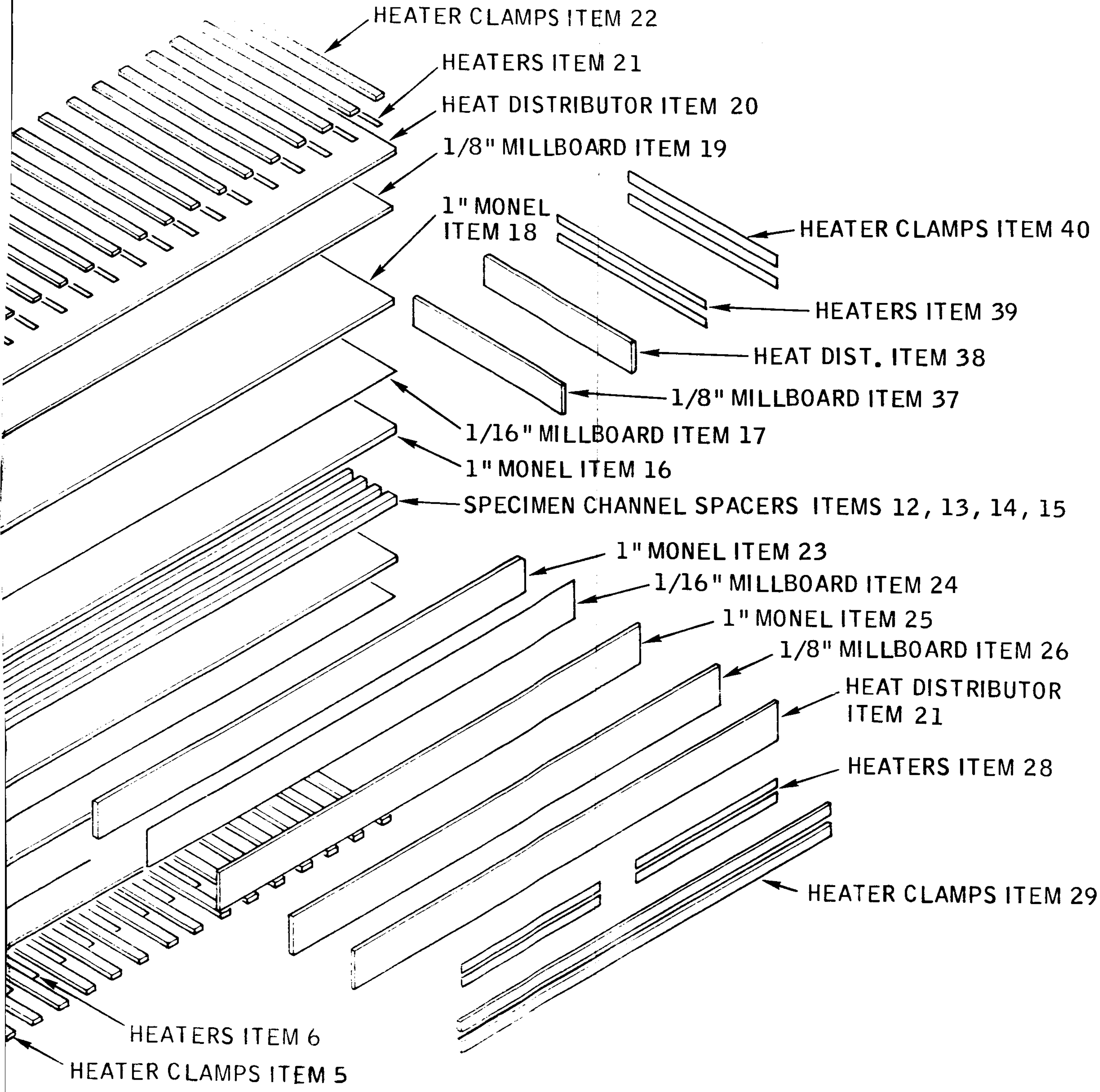
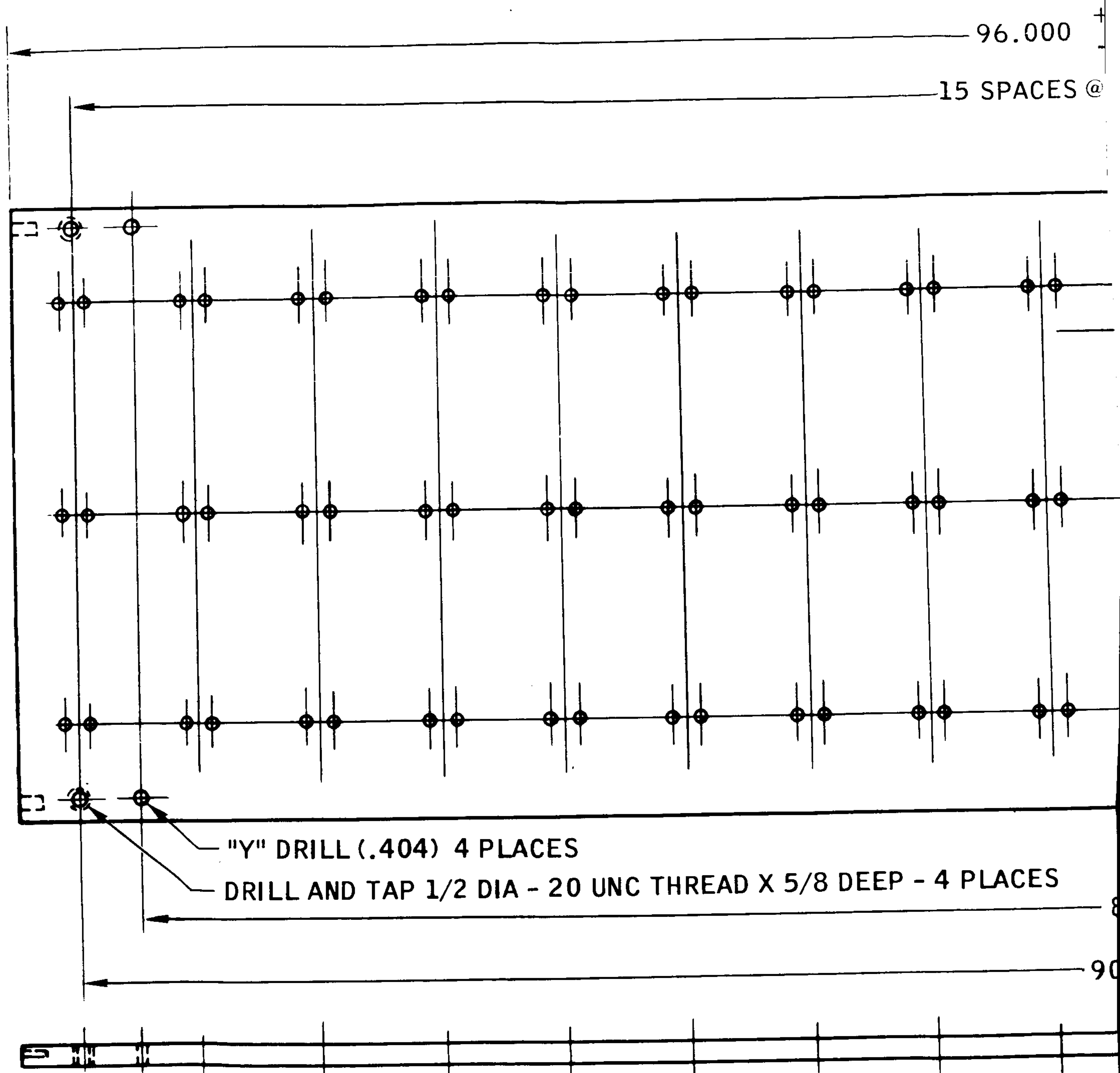


Figure 42. Heater Platten Lay-Up

81


96.000
15 SPACES @
"Y" DRILL (.404) 4 PLACES
DRILL AND TAP 1/2 DIA - 20 UNC THREAD X 5/8 DEEP - 4 PLACES
8
90

B 2

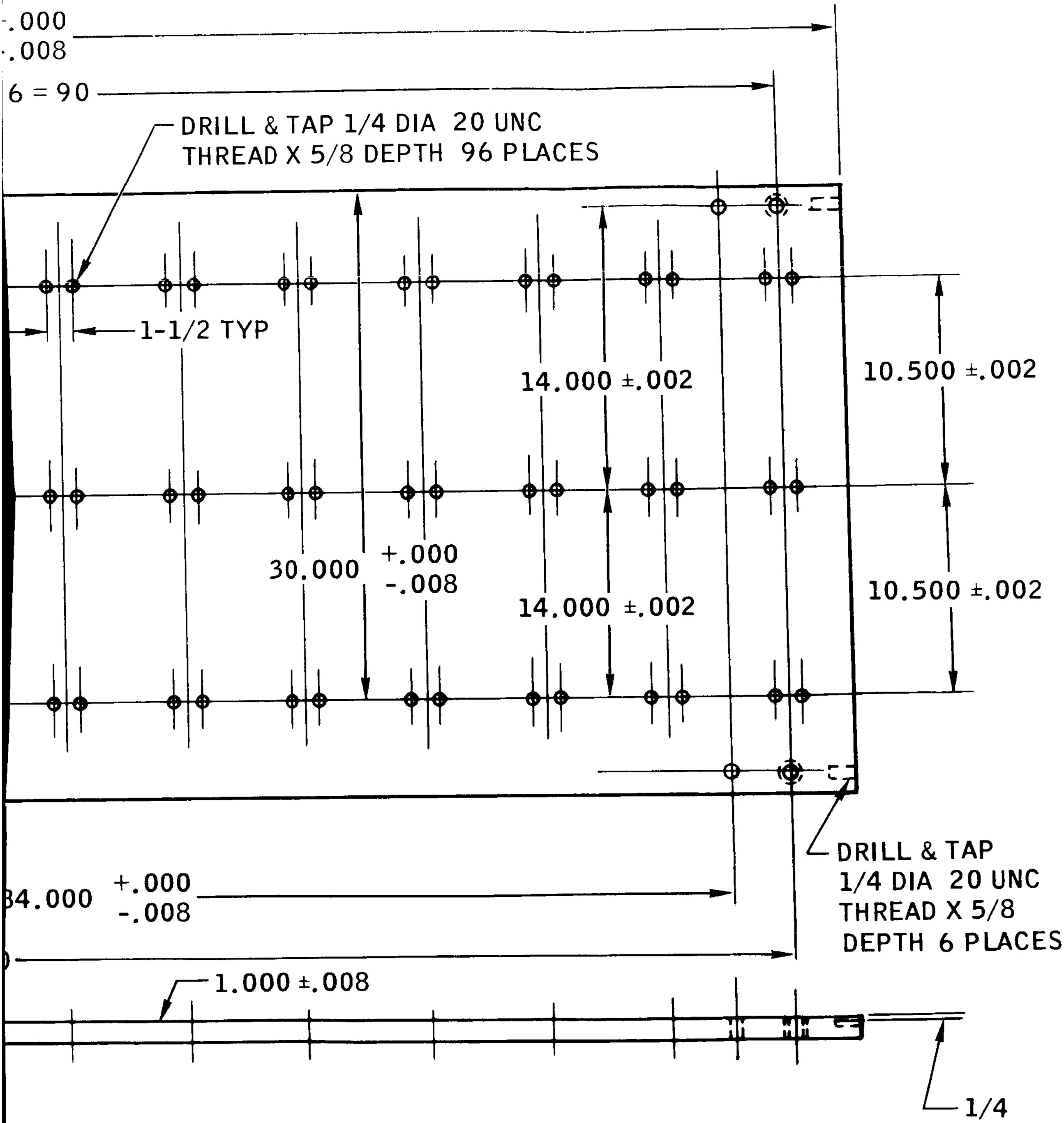
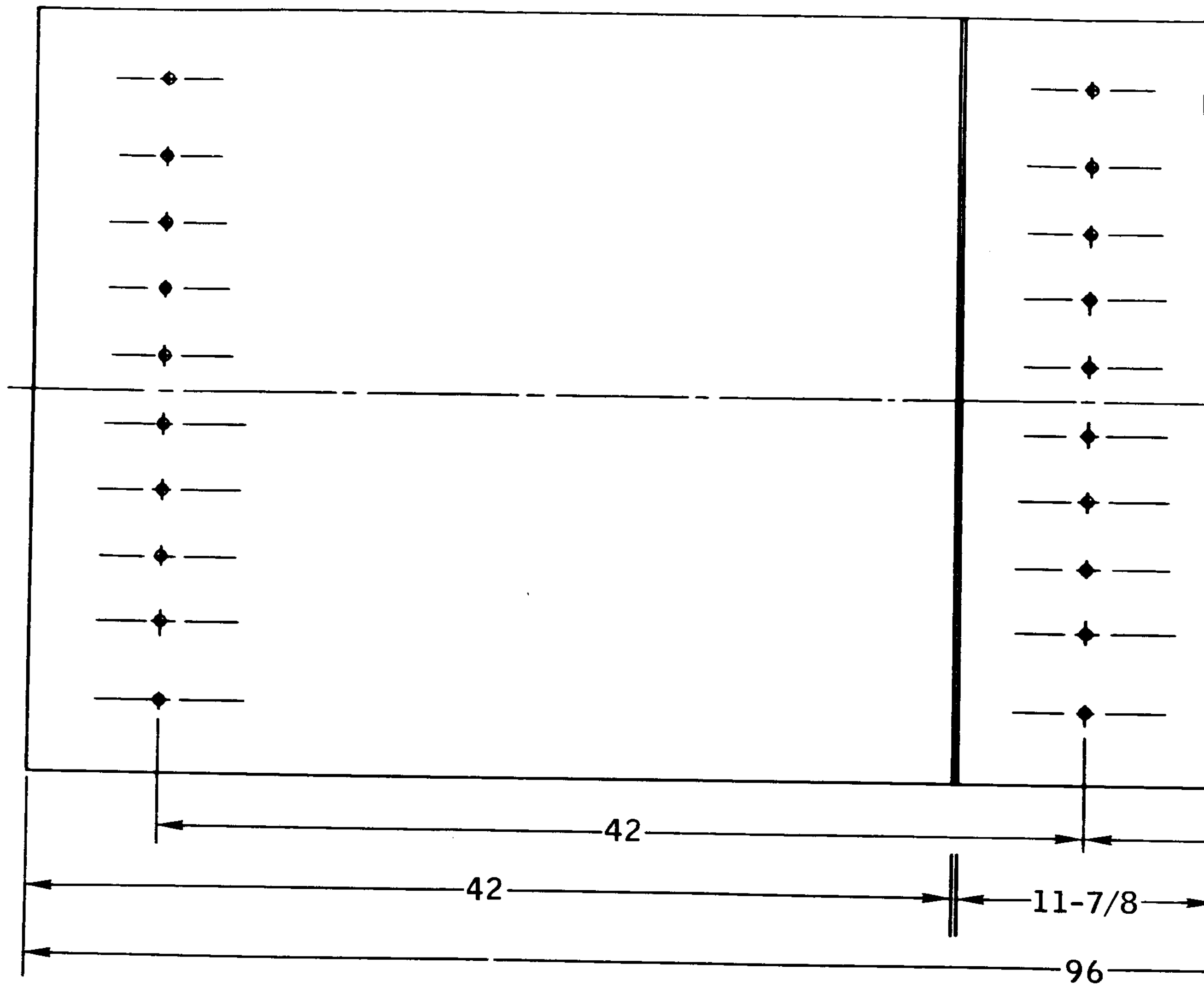


Figure 43. Heater Core Outer Plates (Items 9, 18)

F1



F2

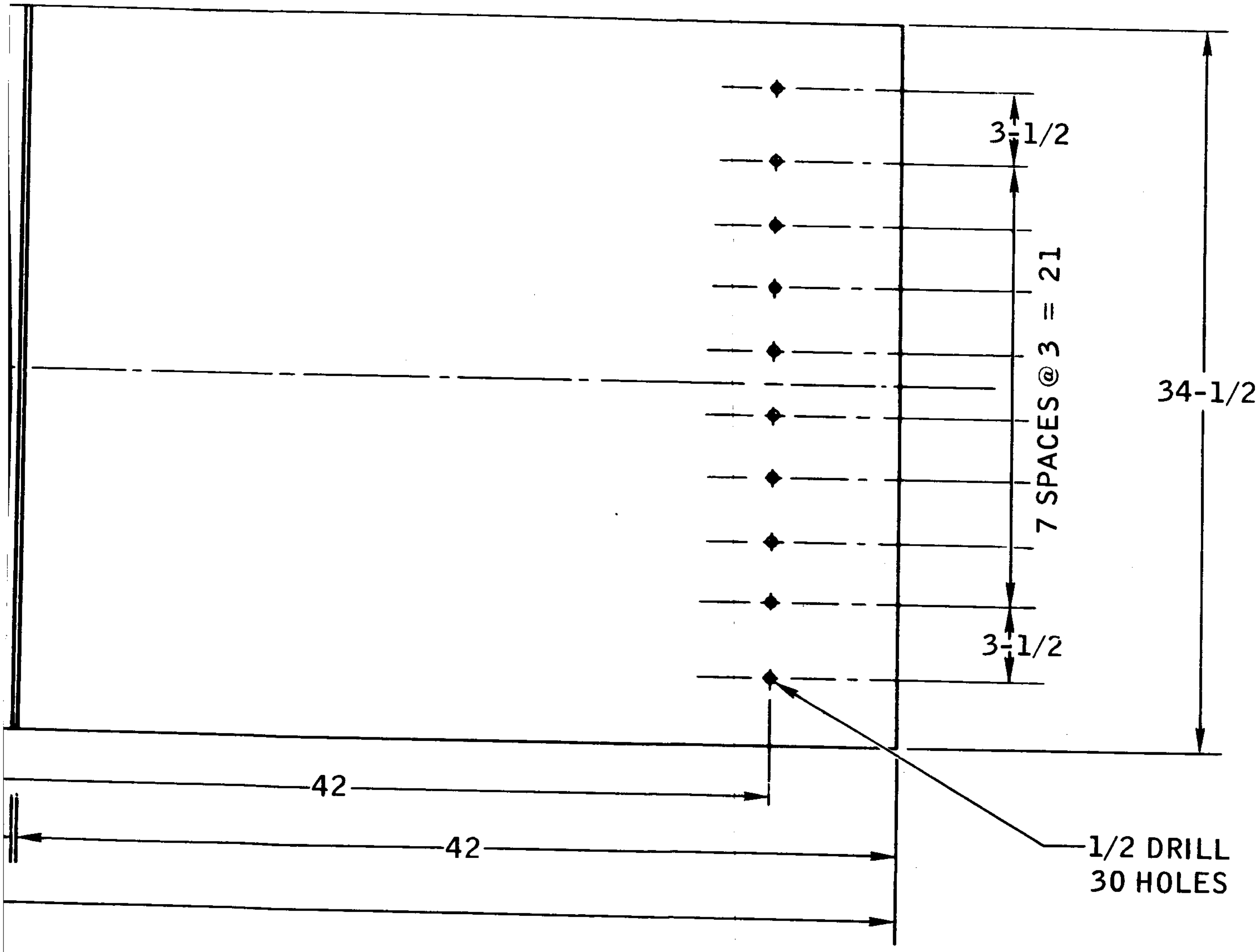
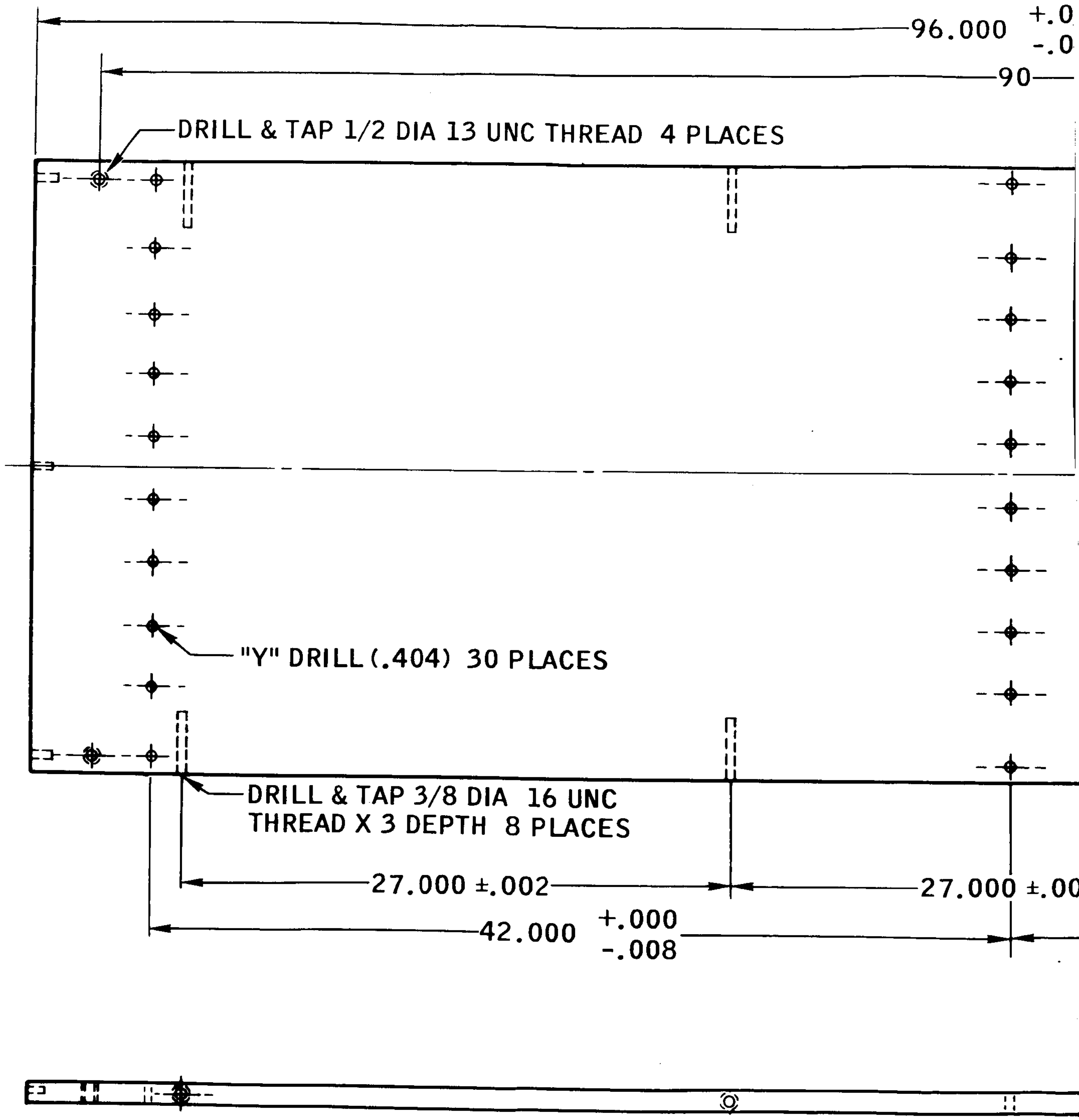


Figure 44. Heater Core Asbestos Separator (item 10, 17)

B1


96.000 +.0 -.0
90
DRILL & TAP 1/2 DIA 13 UNC THREAD 4 PLACES
"Y" DRILL (.404) 30 PLACES
DRILL & TAP 3/8 DIA 16 UNC
THREAD X 3 DEPTH 8 PLACES
27.000 ±.002
27.000 ±.00
42.000 +.000 -.008

B2

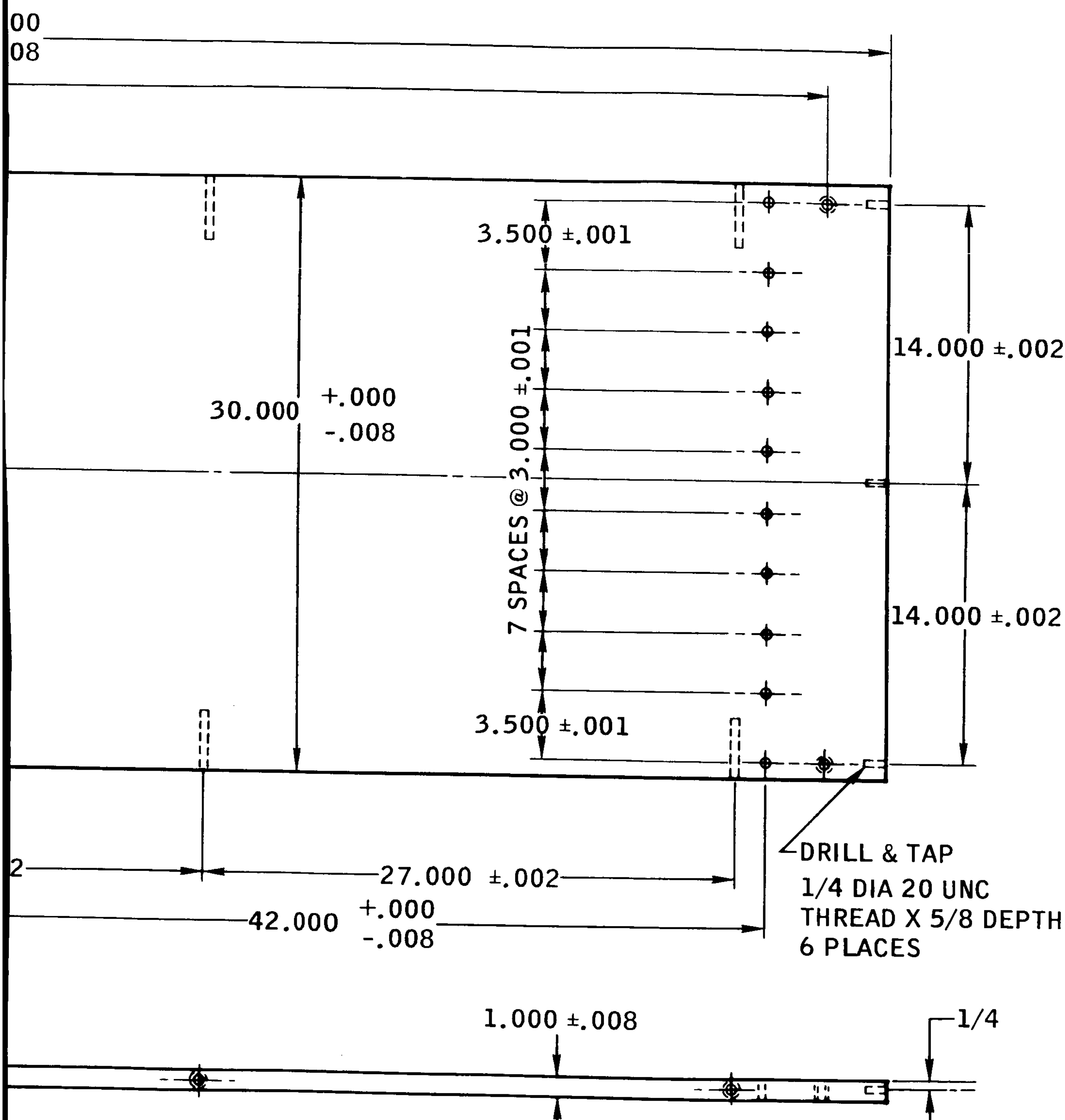
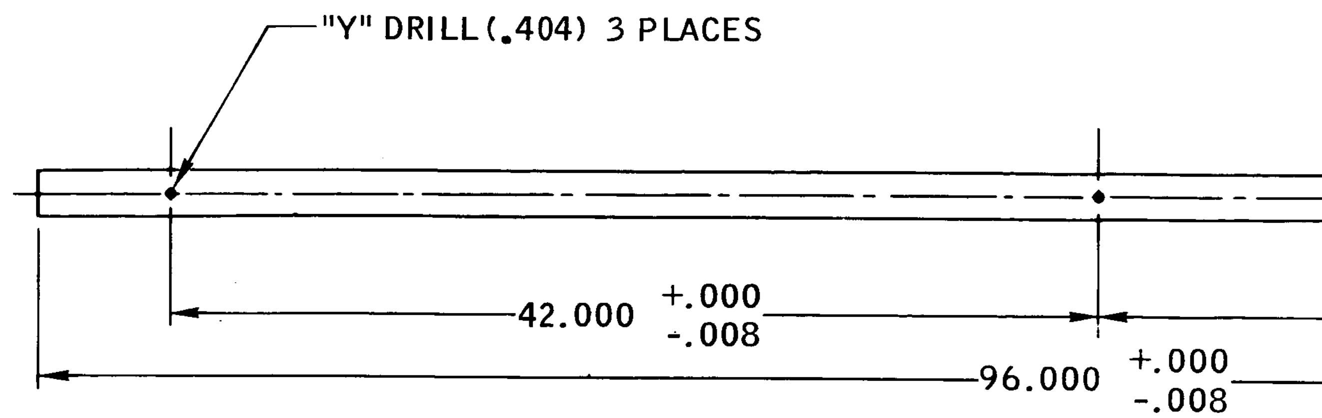
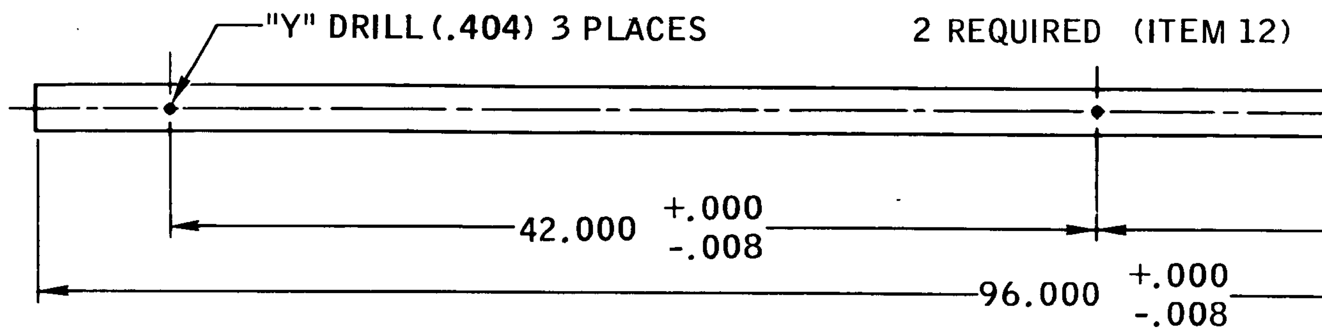


Figure 45. Heater Core Inner Plates (Items 16, 11)

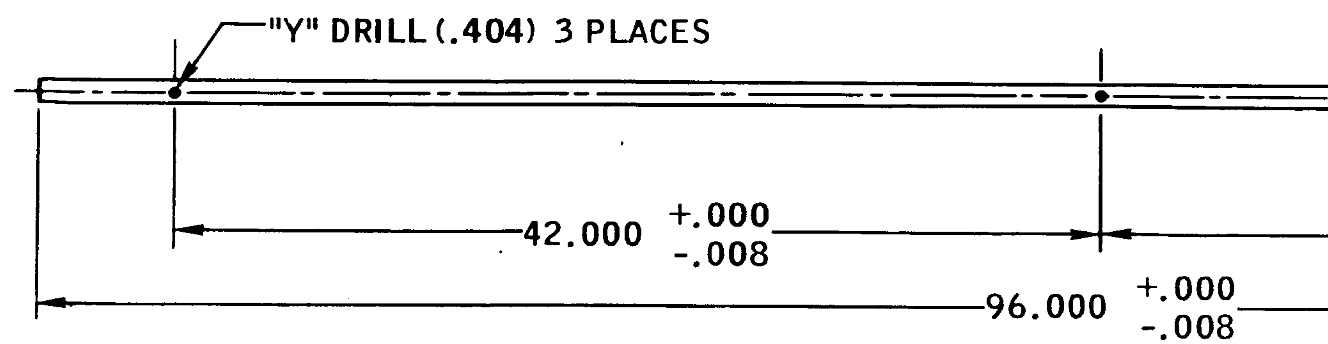
F1



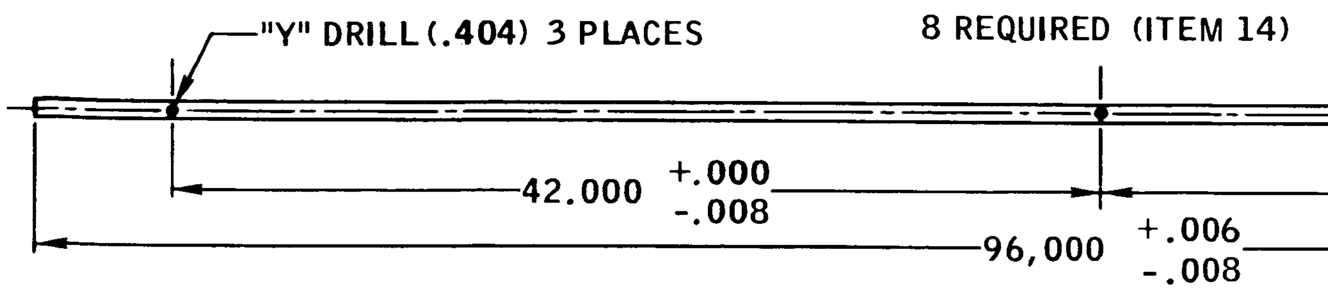
2 REQUIRED (ITEM 12)



2 REQUIRED (ITEM 13)



8 REQUIRED (ITEM 14)



8 REQUIRED (ITEM 15)

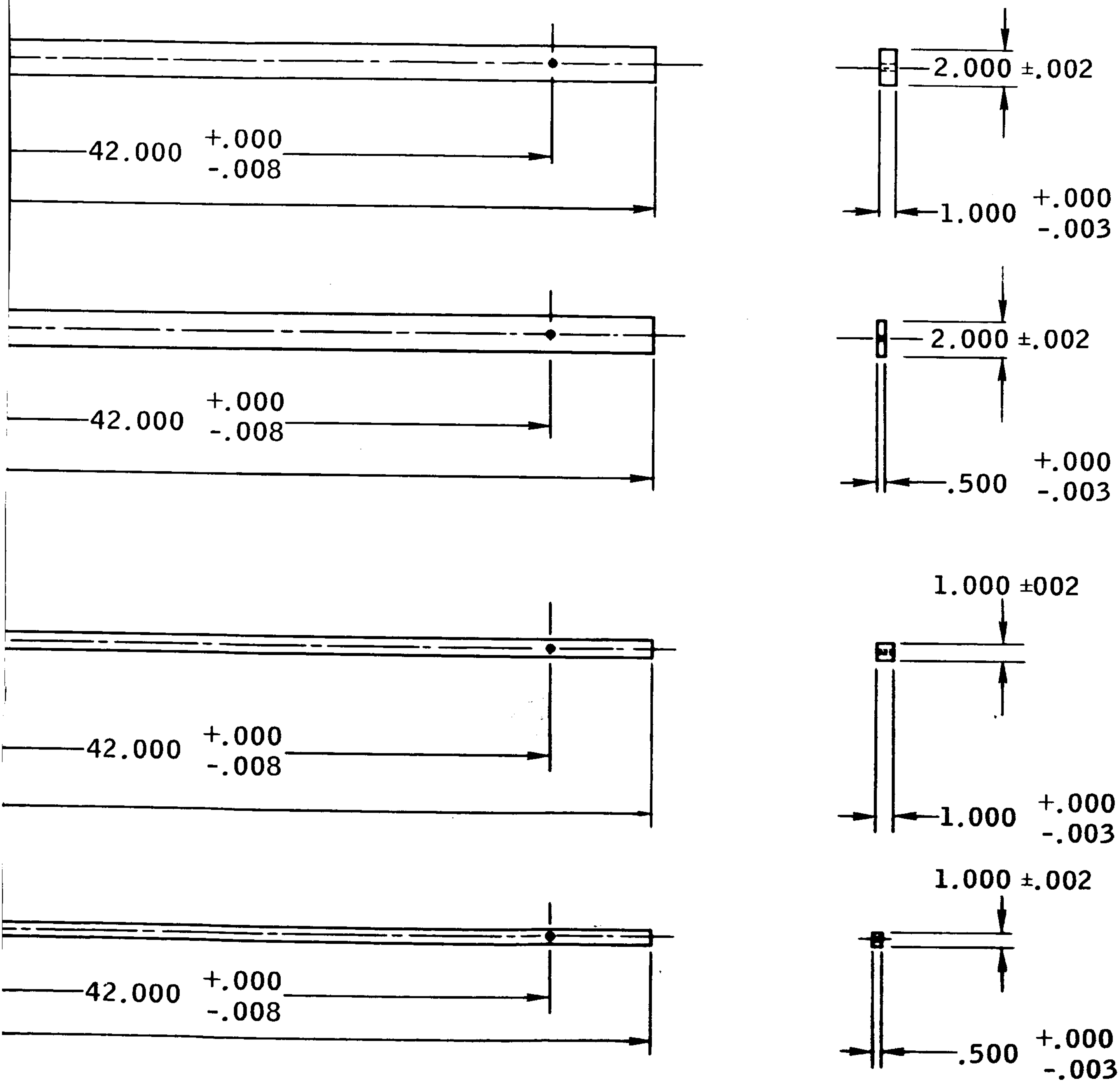
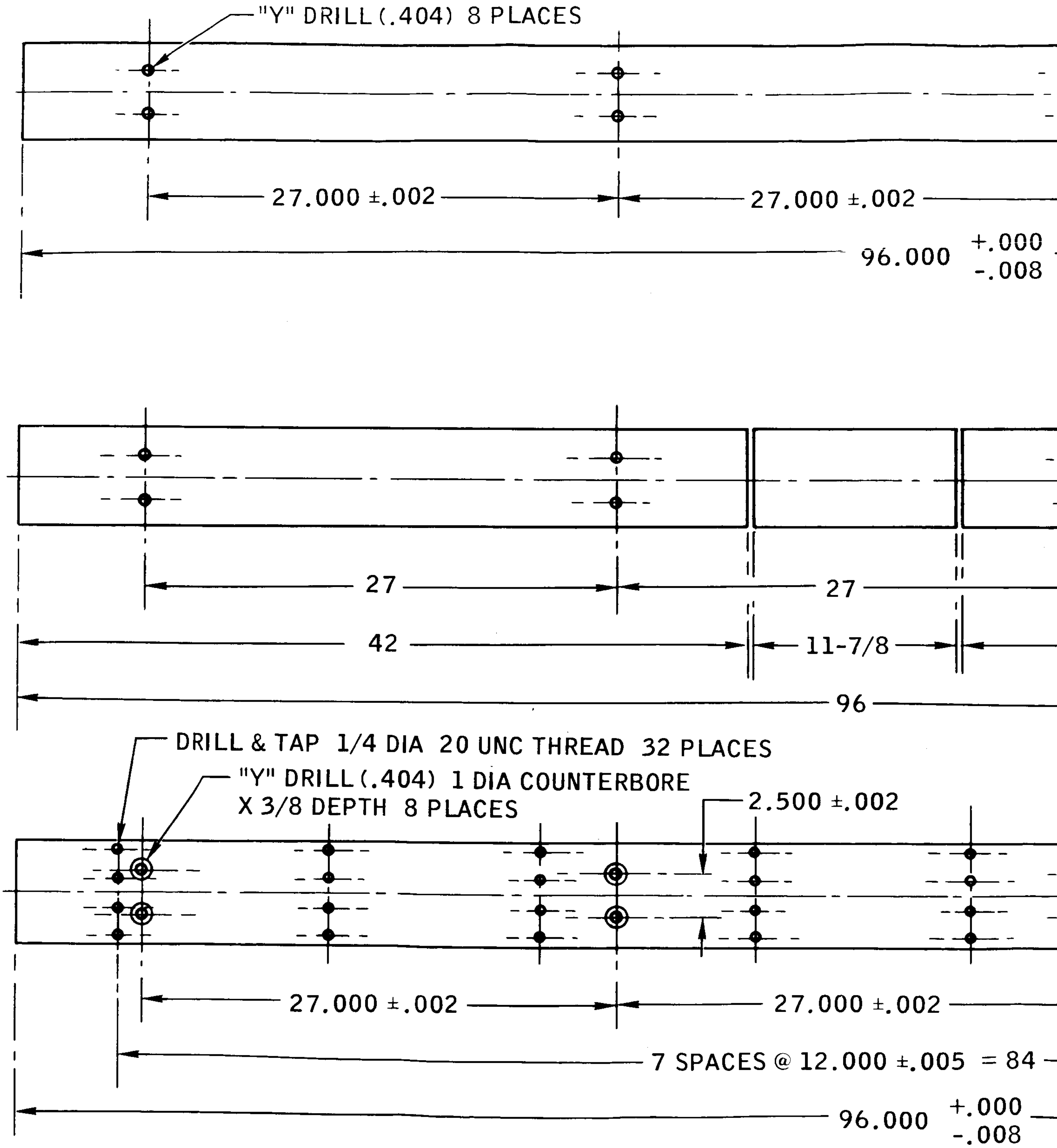


Figure 46. Heater Core Spacers (Items 12, 13, 14, 15)

B1


"Y" DRILL (.404) 8 PLACES
27.000 ±.002
27.000 ±.002
96.000 +.000 -.008
27
27
42
11-7/8
96
DRILL & TAP 1/4 DIA 20 UNC THREAD 32 PLACES
"Y" DRILL (.404) 1 DIA COUNTERBORE
X 3/8 DEPTH 8 PLACES
2.500 ±.002
27.000 ±.002
27.000 ±.002
7 SPACES @ 12.000 ±.005 = 84
96.000 +.000 -.008

B2

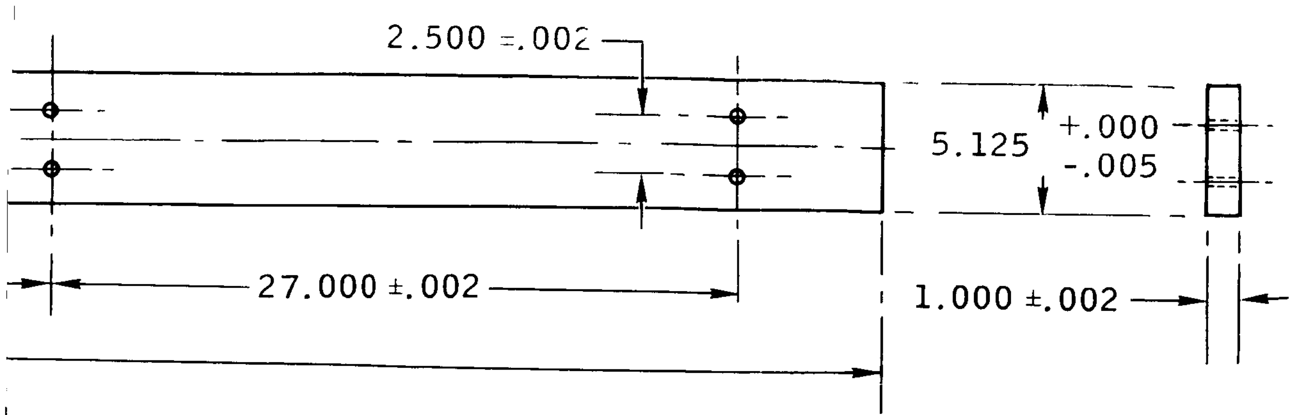


Figure 47. Heater Core Outer Side Plates (Item 23, 30)

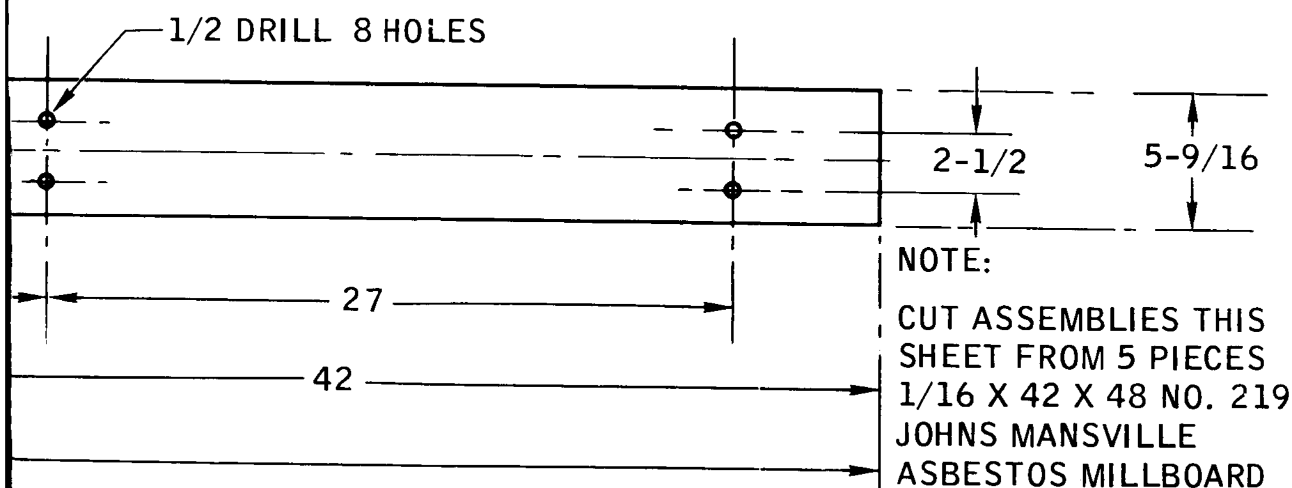


Figure 48. Heater Core Side Asbestos Separator (Item 24, 31)

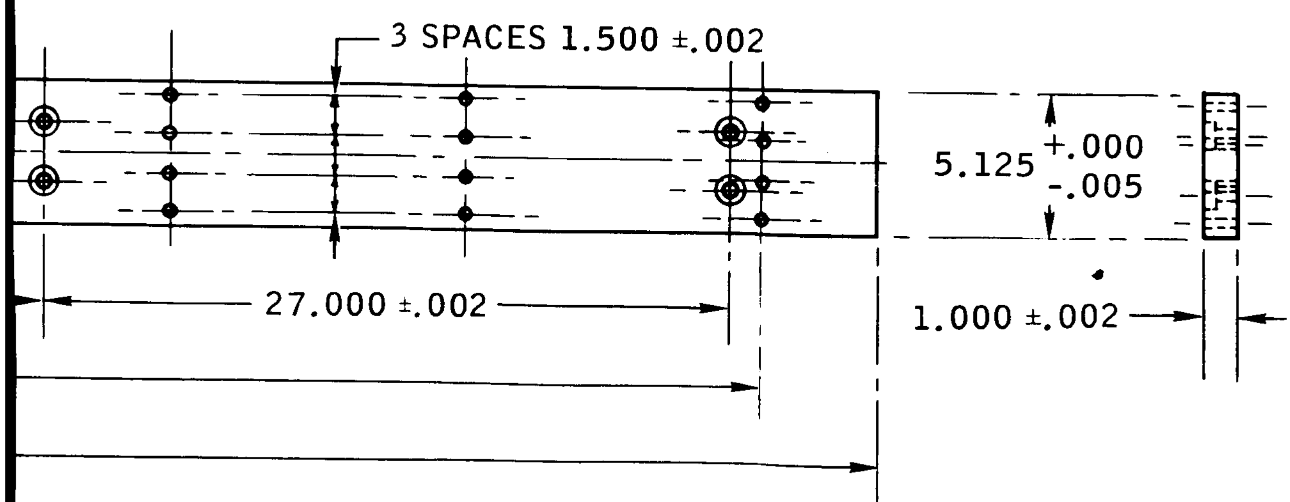
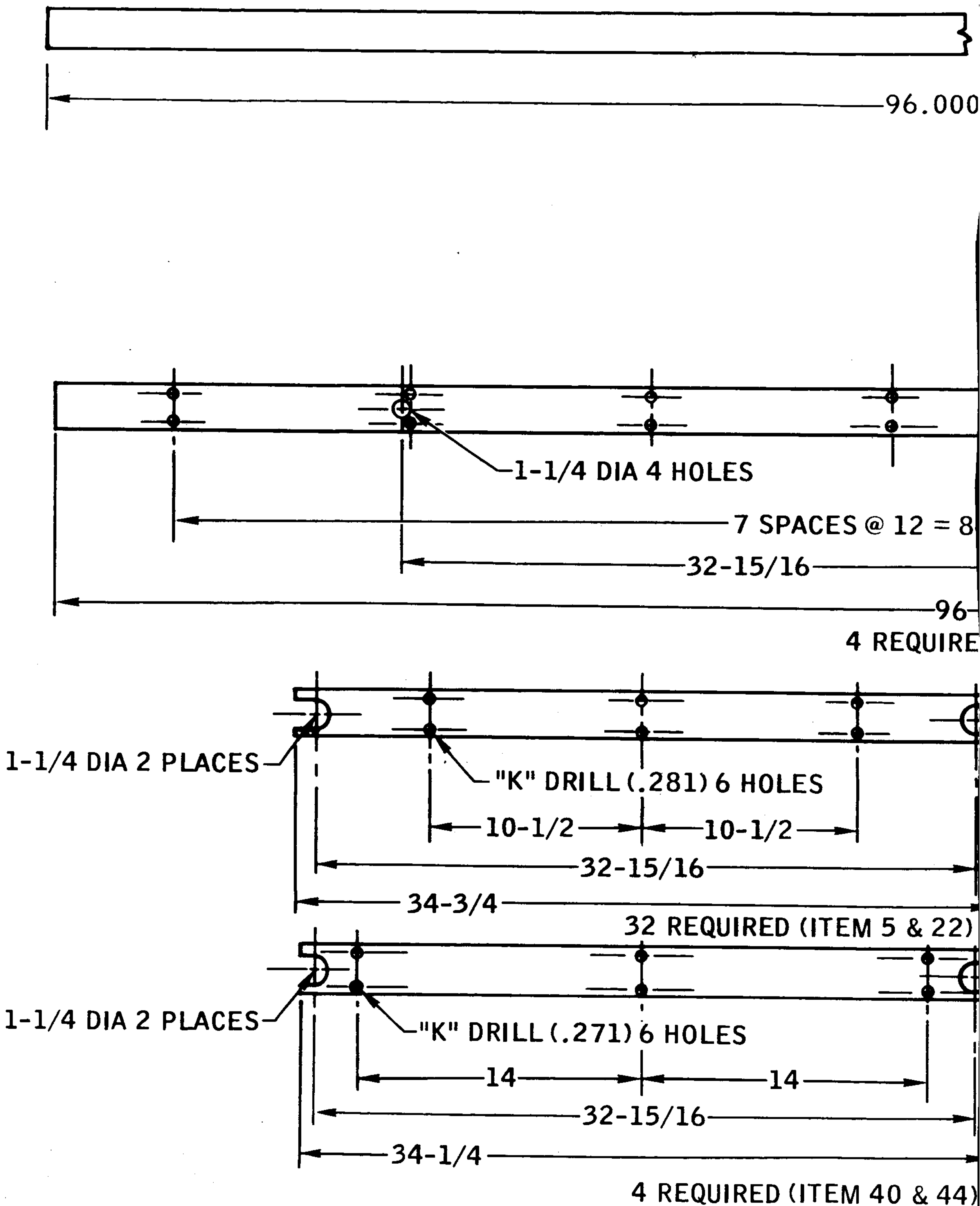


Figure 49. Heater Core Inner Side Plates (Item 25, 32)

F1


96.000
1-1/4 DIA 4 HOLES
7 SPACES @ 12 = 8
32-15/16
96
4 REQUIRE
1-1/4 DIA 2 PLACES
"K" DRILL (.281) 6 HOLES
10-1/2
10-1/2
32-15/16
34-3/4
32 REQUIRED (ITEM 5 & 22)
1-1/4 DIA 2 PLACES
"K" DRILL (.271) 6 HOLES
14
14
32-15/16
34-1/4
4 REQUIRED (ITEM 40 & 44)

F2

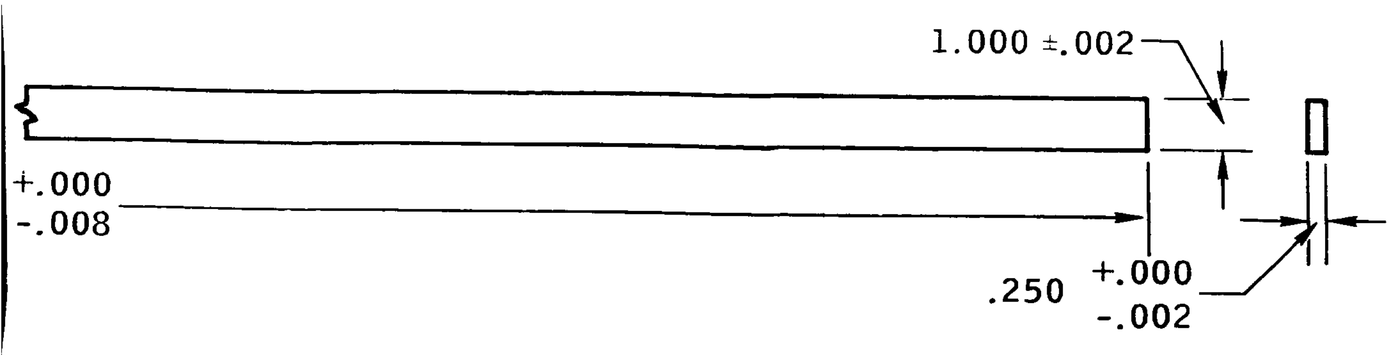


Figure 50. Filler Bar (Item 23, 25, 30, 32)

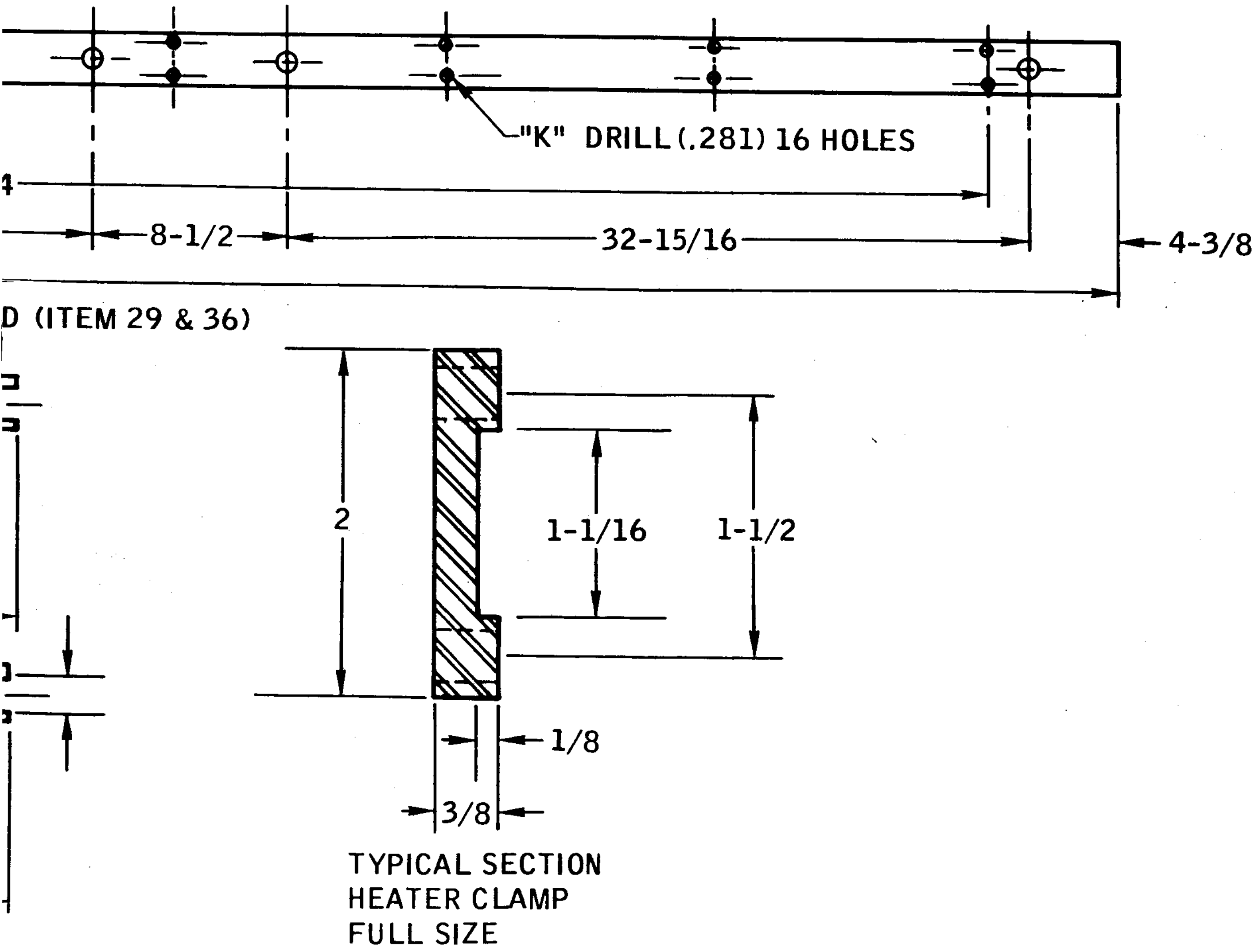
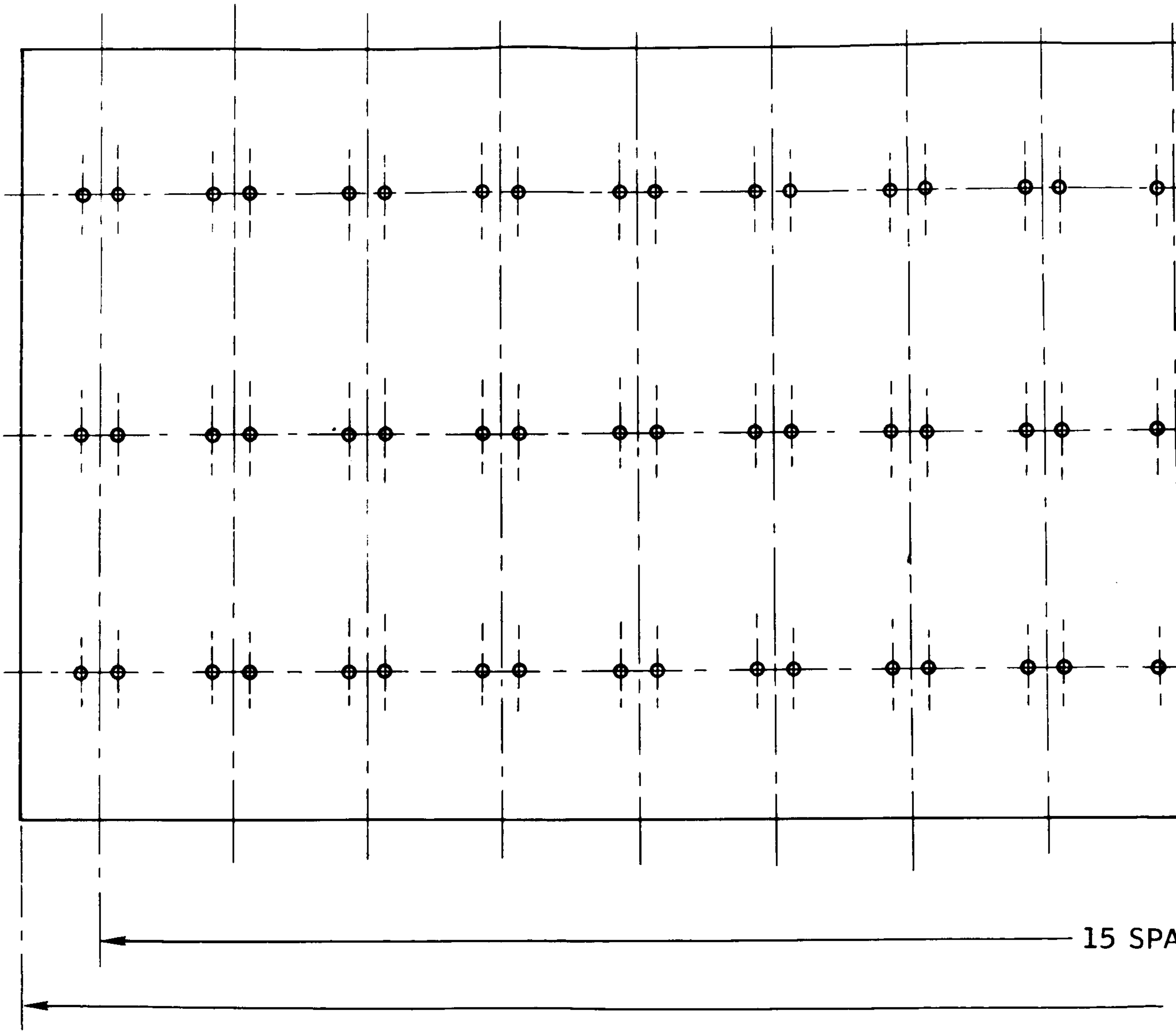


Figure 51. Heater Clamps (Item 5, 29, 22, 36, 40, 44)

B1



2 REQUIRED

B2

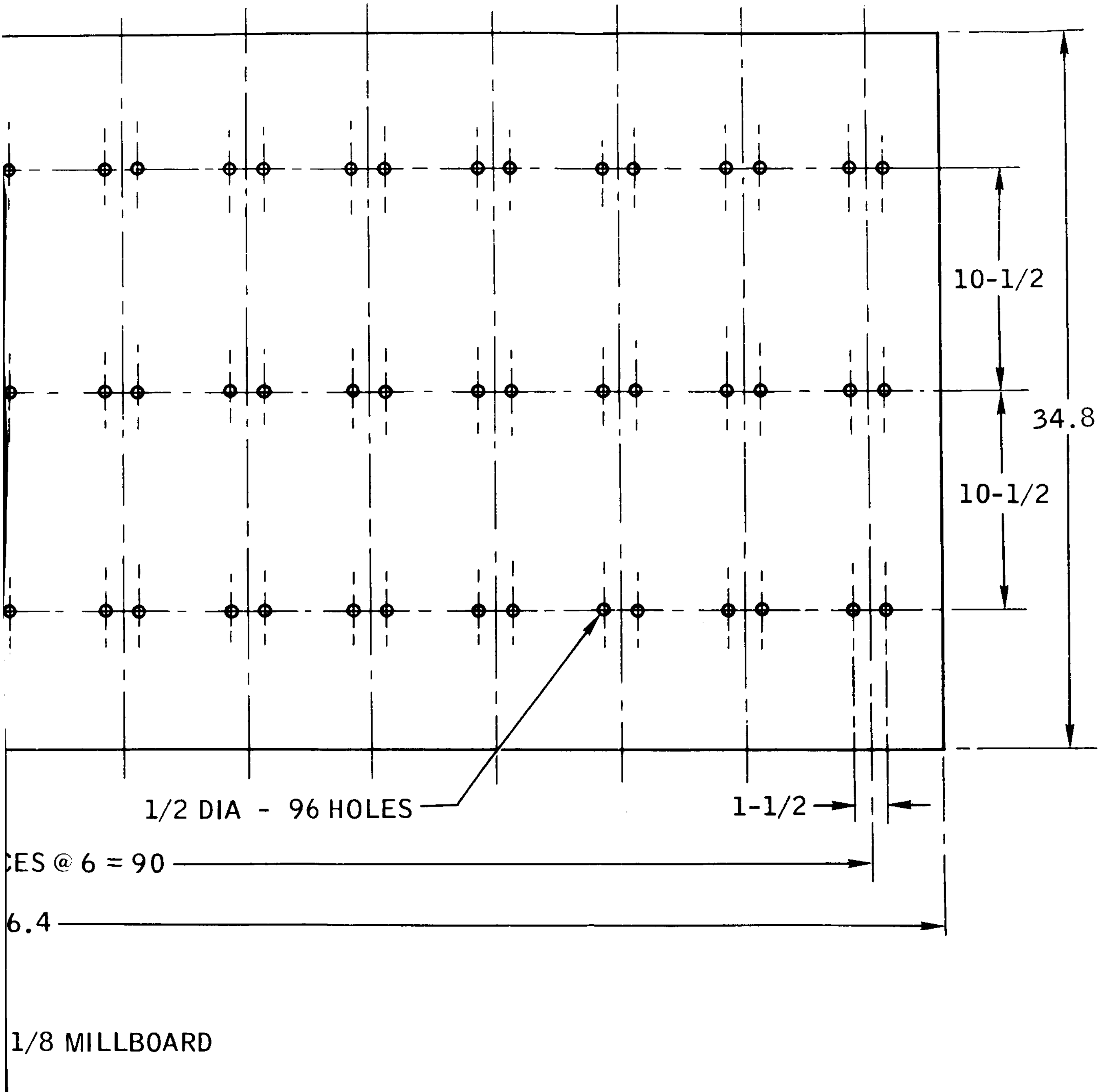
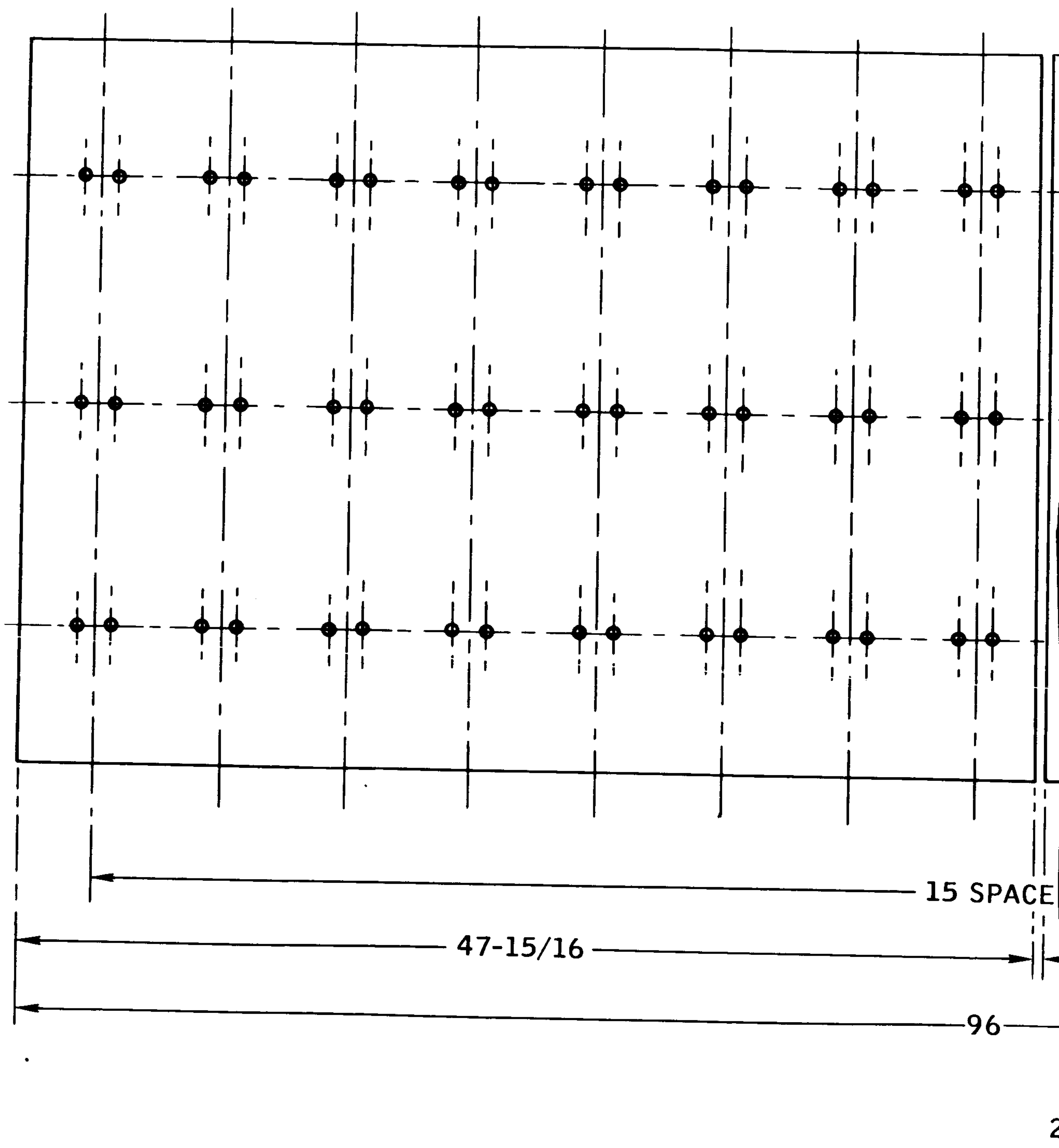


Figure 52. Top And Bottom Heat Distributor Plates (Item 7, 20)

F1



F2

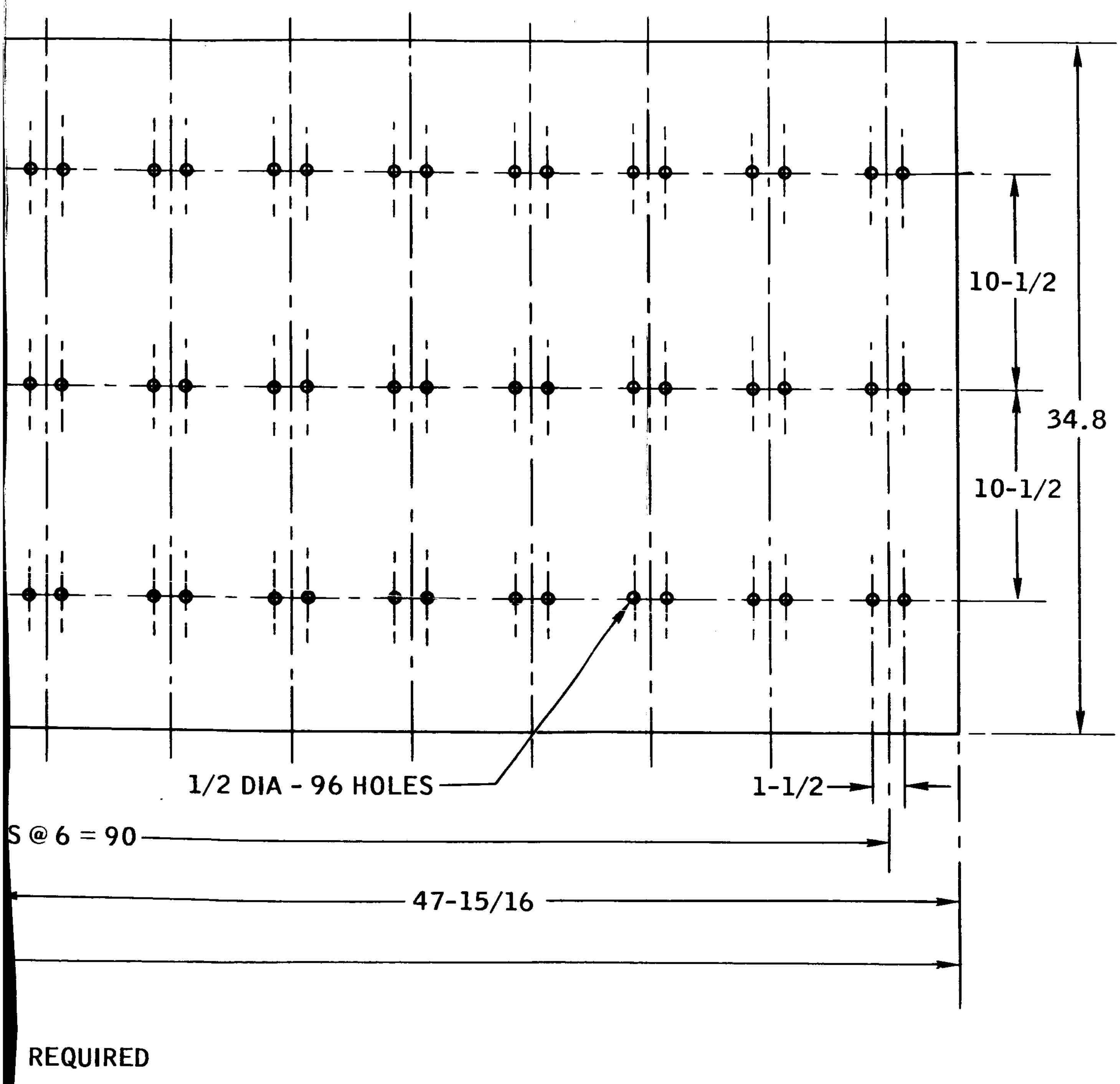
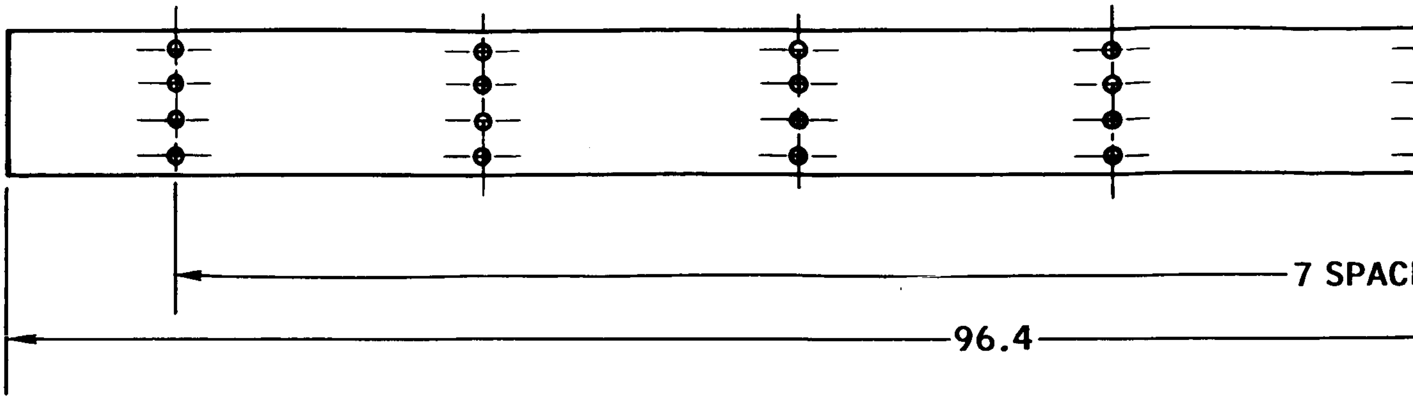
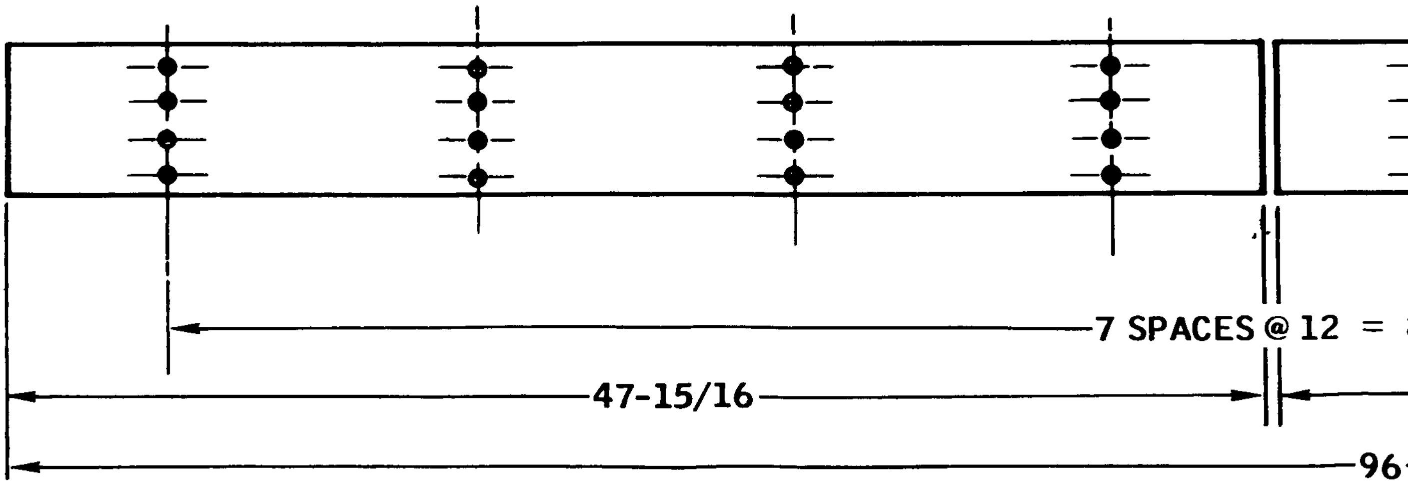


Figure 53. Asbestos Heat Distributor Separator (Item 8, 19)

B1



2 REQUIRED



2 REQUIRED - 1/8

B2

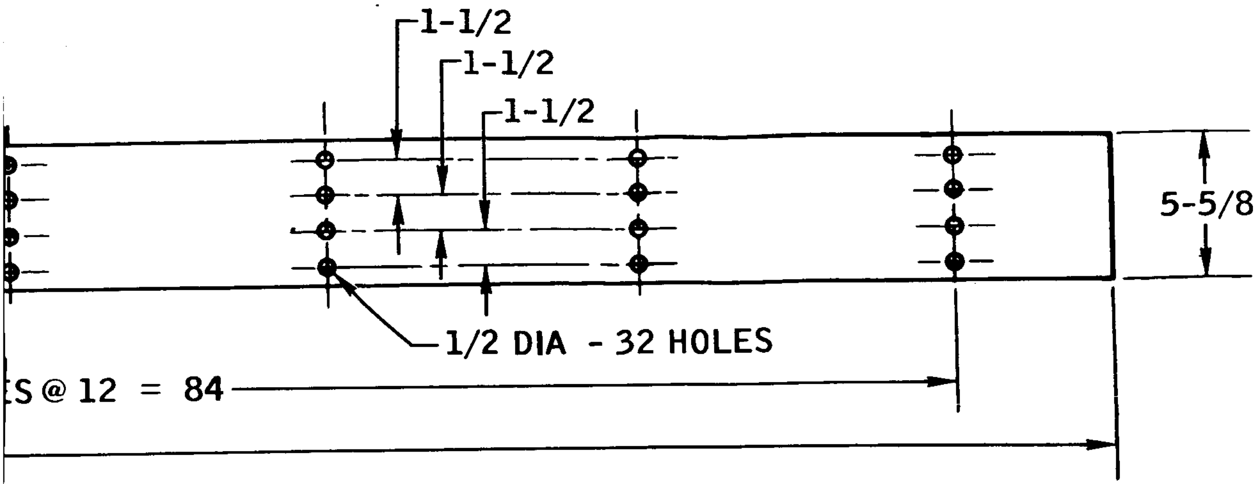


Figure 54. Side Heat Distributor Plates (Item 27, 34)

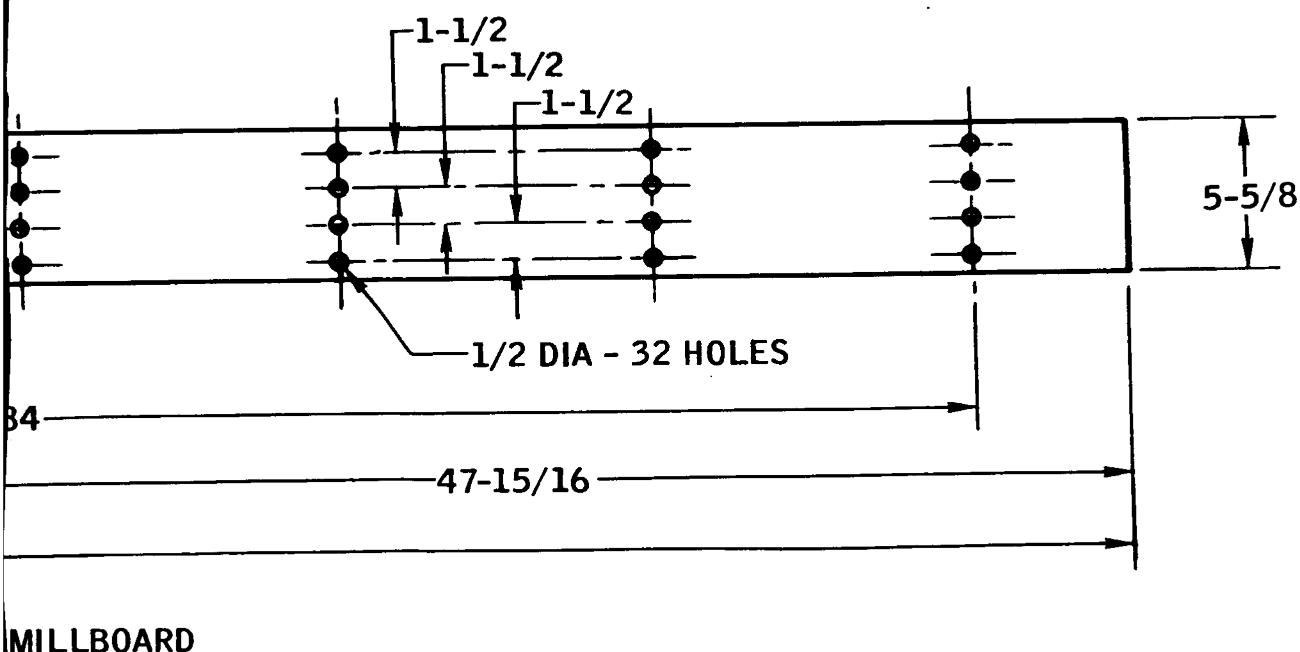


Figure 55. Asbestos Heat Distributor Separator (Item 26, 33)

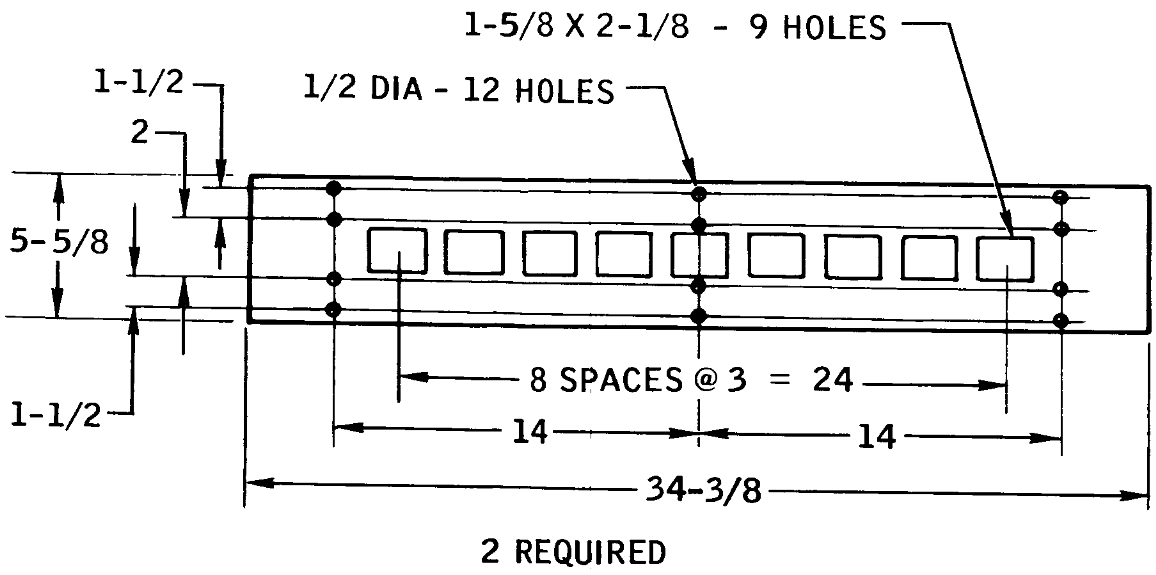


Figure 56. **Heat Distributor End Plates (Item 38, 42)**

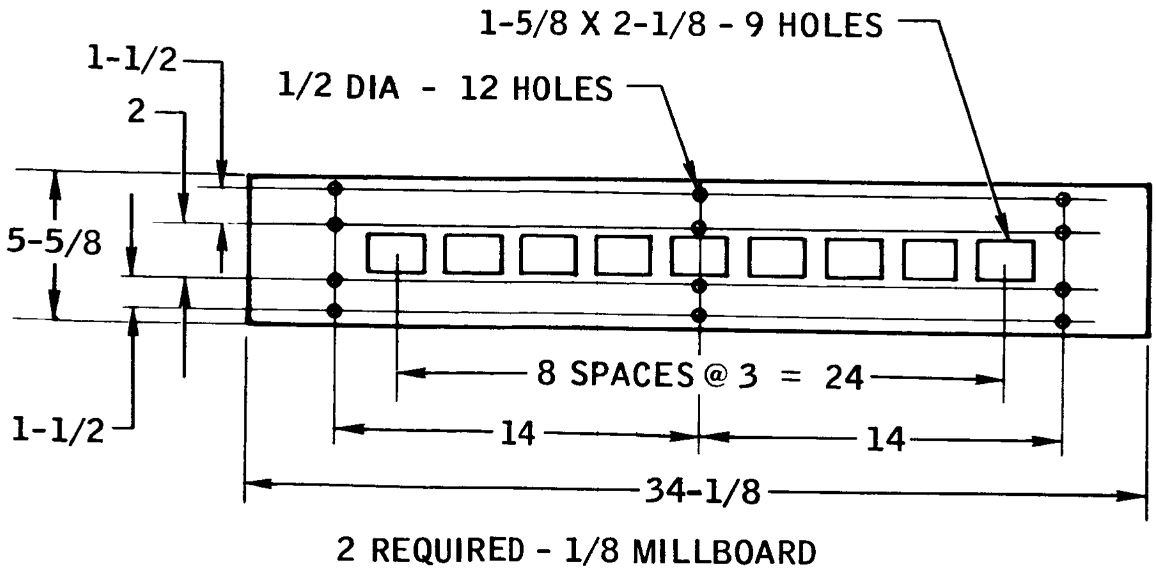
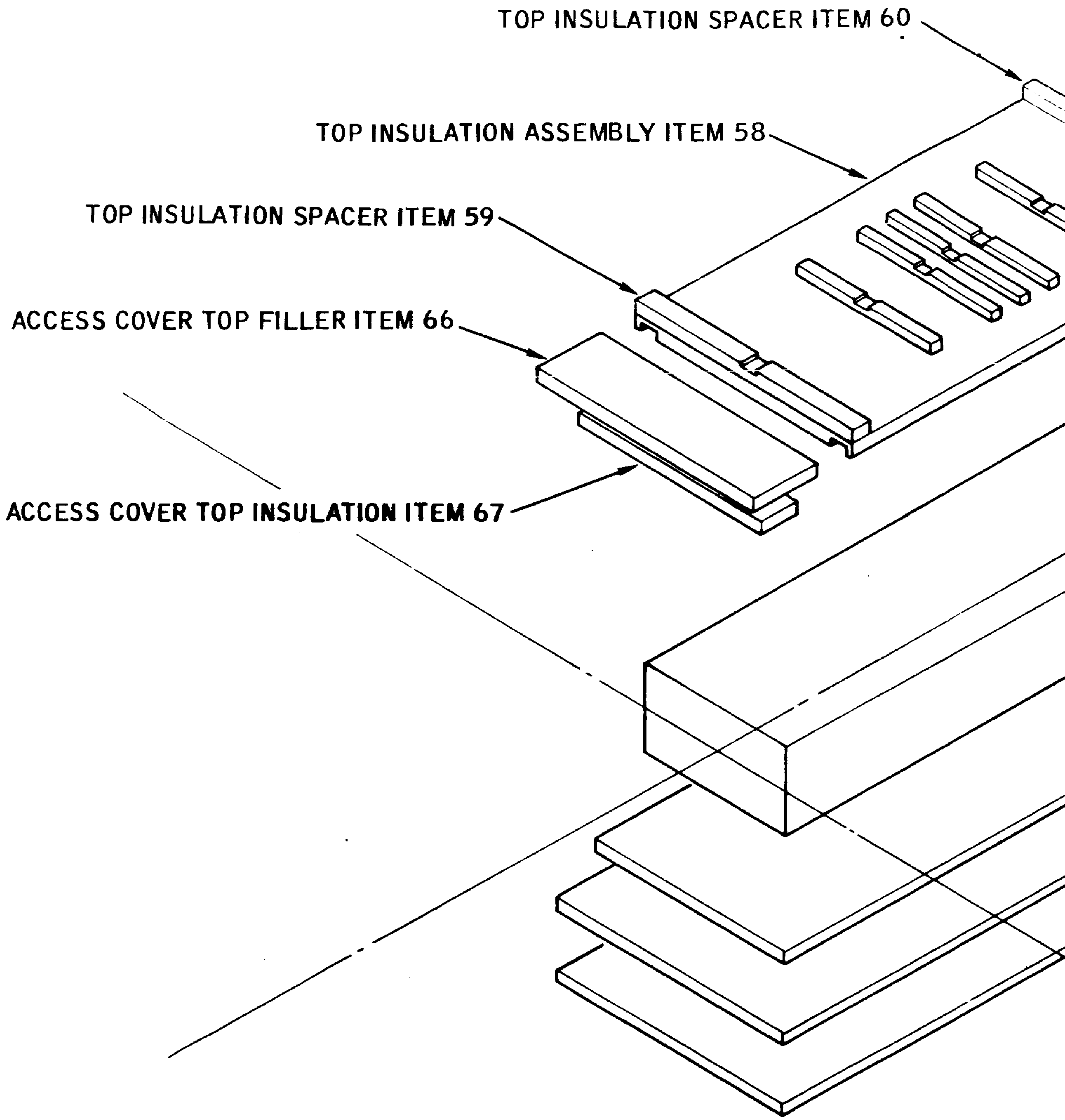


Figure 57. **Asbestos Heat Distributor Separator (Item 37, 41)**


TOP INSULATION SPACER ITEM 60
TOP INSULATION ASSEMBLY ITEM 58
TOP INSULATION SPACER ITEM 59
ACCESS COVER TOP FILLER ITEM 66
ACCESS COVER TOP INSULATION ITEM 67

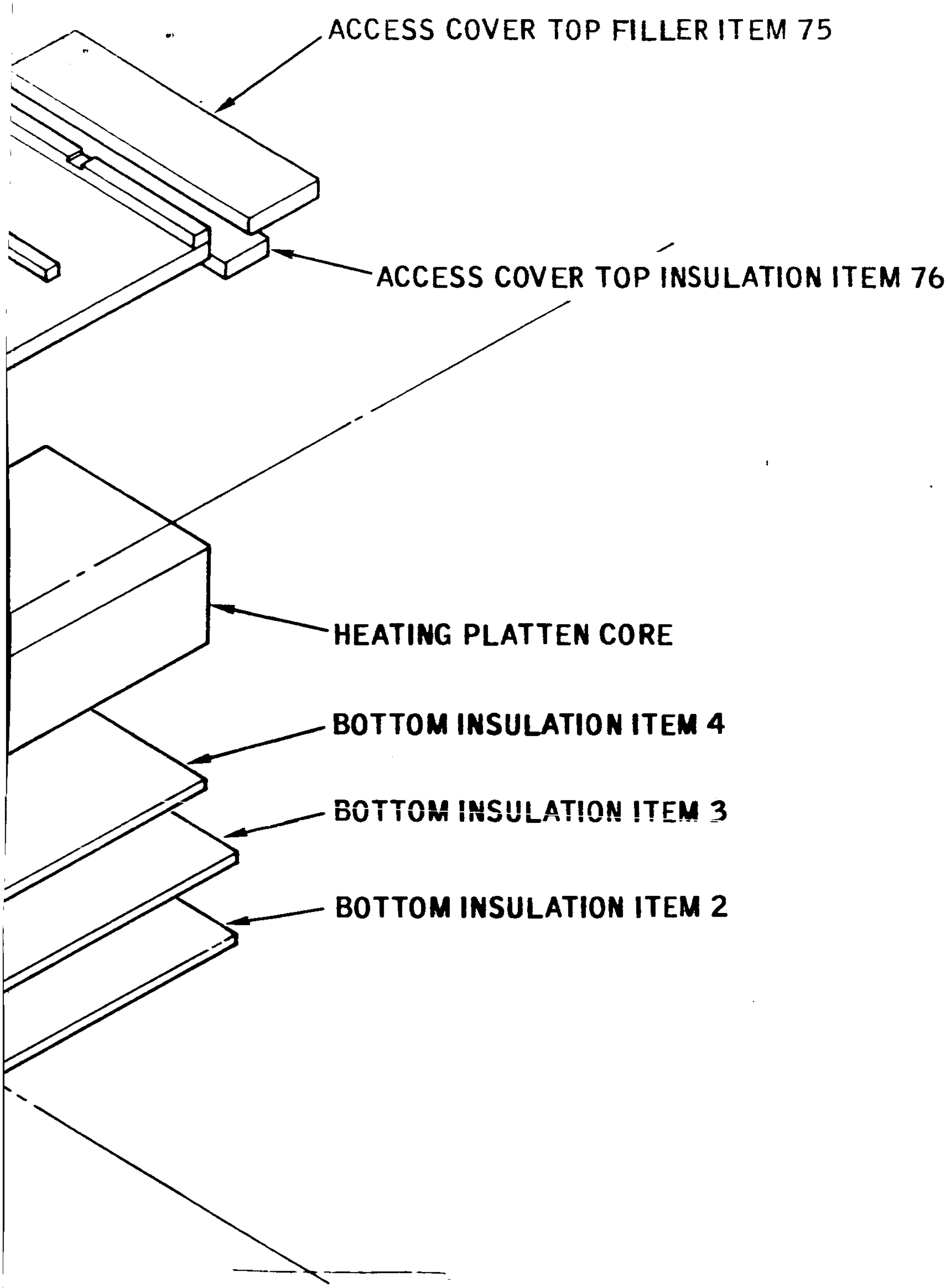
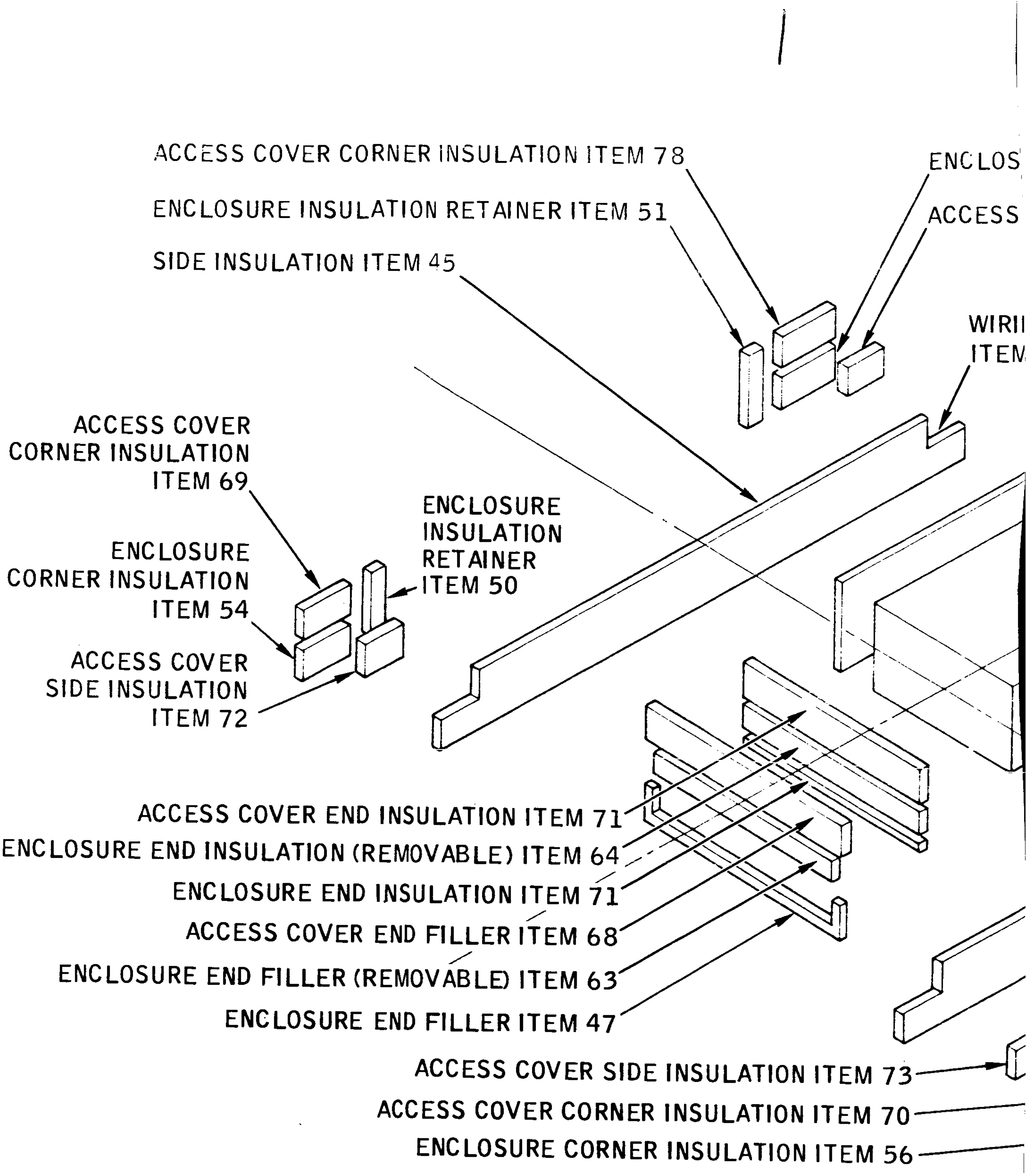


Figure 58. Heater Platten Insulation Lay-Up - Top and Bottom



ACCESS COVER CORNER INSULATION ITEM 78
ENCLOSURE INSULATION RETAINER ITEM 51
SIDE INSULATION ITEM 45
ENCLOS
ACCESS
WIRI
ITEM
ACCESS COVER CORNER INSULATION ITEM 69
ENCLOSURE INSULATION RETAINER ITEM 50
ENCLOSURE CORNER INSULATION ITEM 54
ACCESS COVER SIDE INSULATION ITEM 72
ACCESS COVER END INSULATION ITEM 71
ENCLOSURE END INSULATION (REMOVABLE) ITEM 64
ENCLOSURE END INSULATION ITEM 71
ACCESS COVER END FILLER ITEM 68
ENCLOSURE END FILLER (REMOVABLE) ITEM 63
ENCLOSURE END FILLER ITEM 47
ACCESS COVER SIDE INSULATION ITEM 73
ACCESS COVER CORNER INSULATION ITEM 70
ENCLOSURE CORNER INSULATION ITEM 56

2

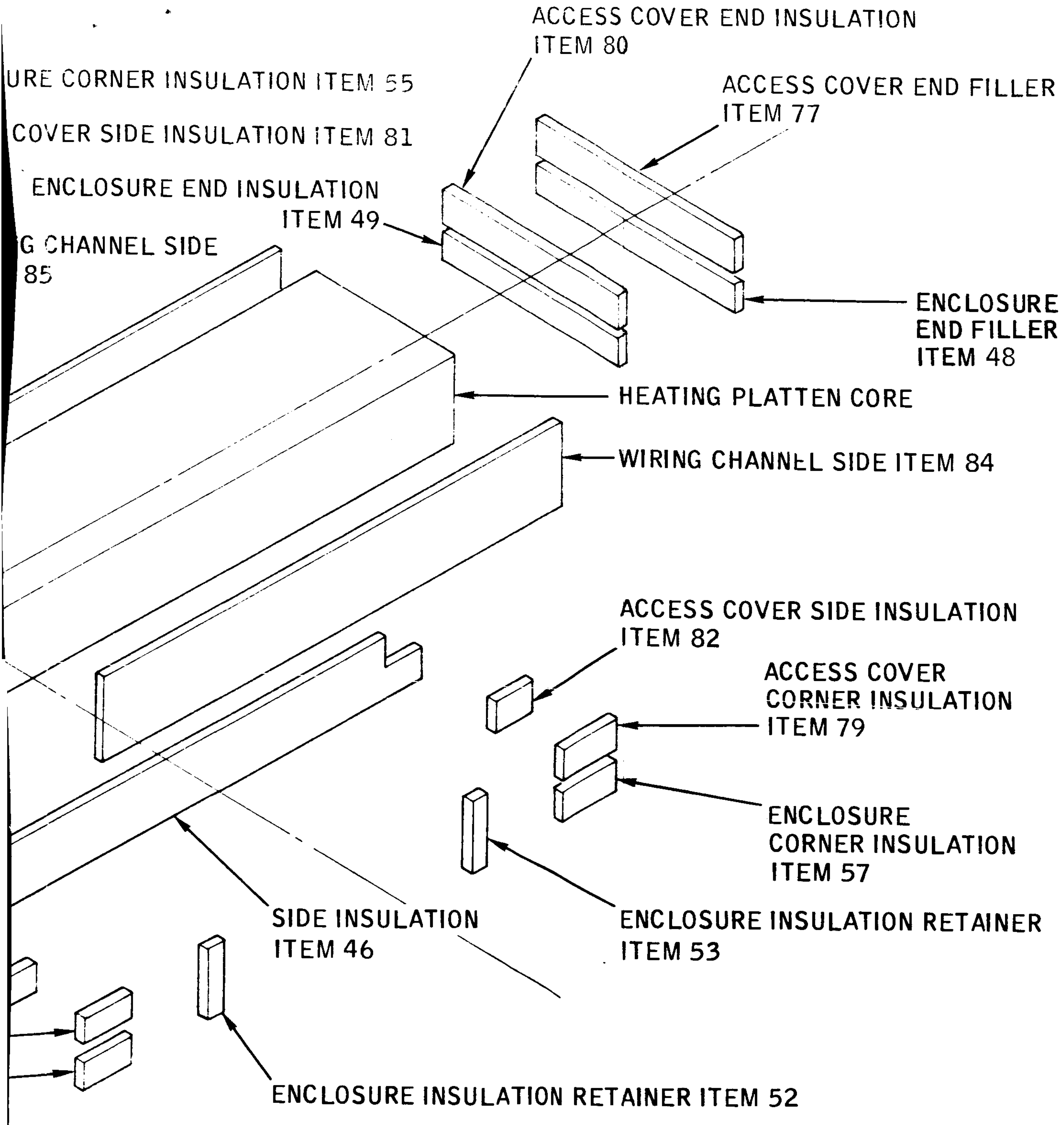


Figure 59. Heating Unit Insulation Lay-Up - Side and End

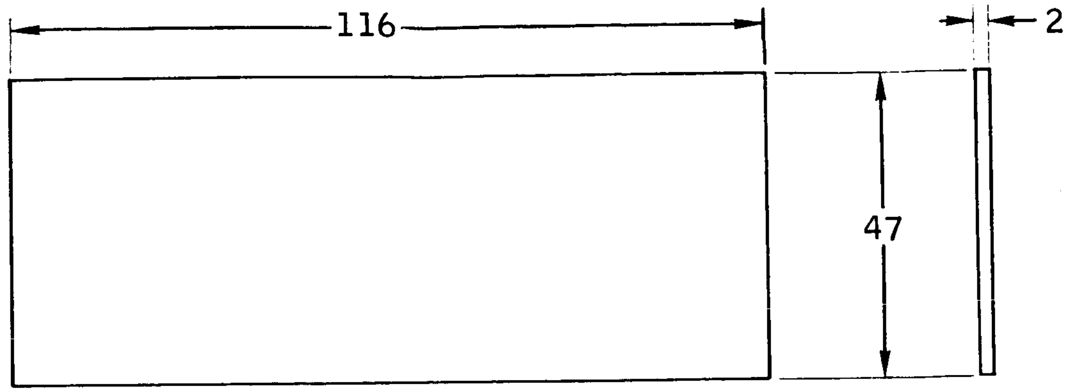


Figure 60. Bottom Insulation Panel (Item 2 & 3)

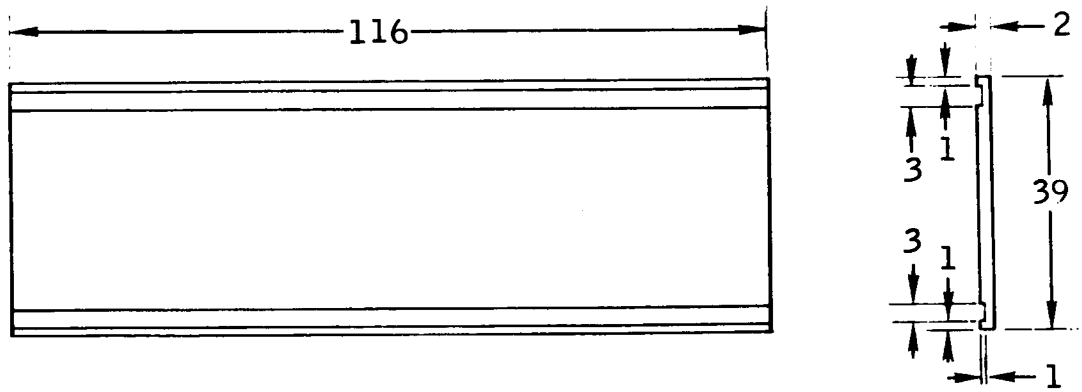


Figure 61. Bottom Insulation Panel (Item 4)

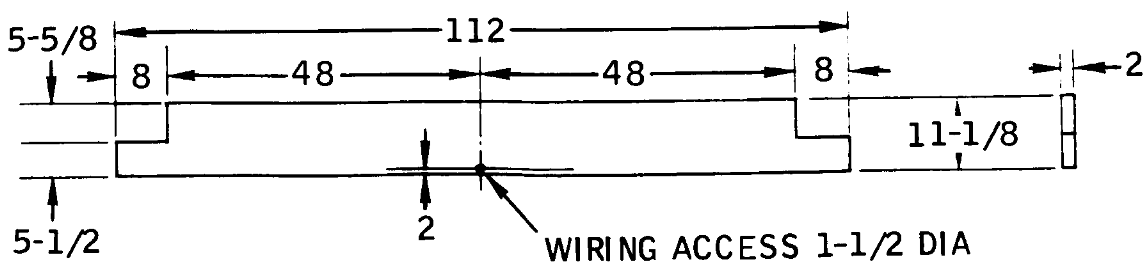


Figure 62. Side Insulation Panel (Item 45 & 46)

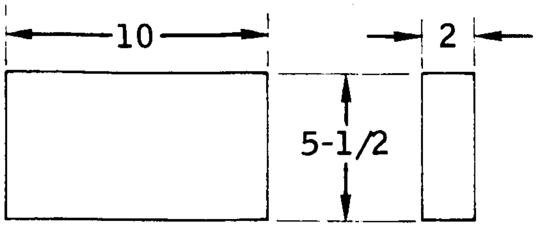


Figure 63. Enclosure Corner Insulation Blocks (Item 54, 55, 56, 57)

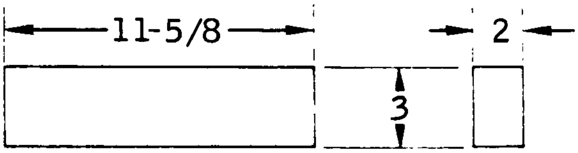


Figure 64. Enclosure Side Retaining Blocks (Item 50, 51, 52, 53)

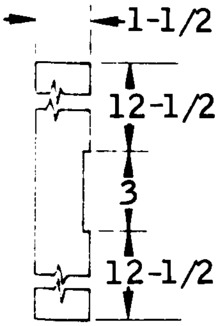


Figure 9 Detail

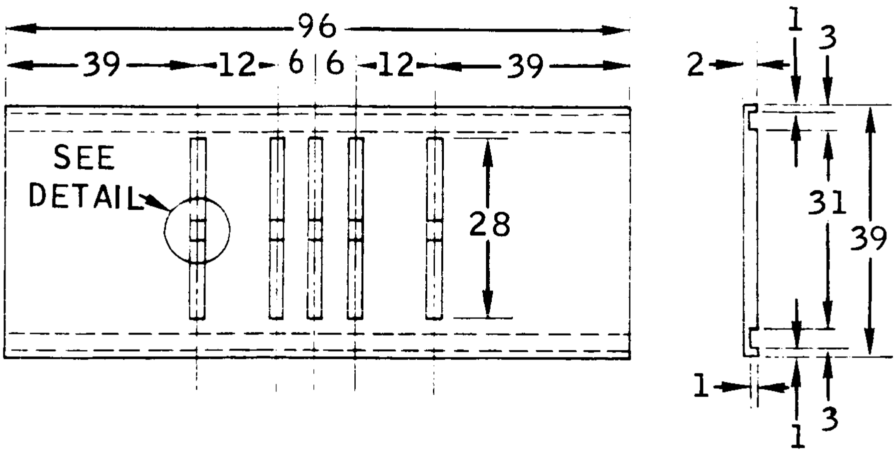


Figure 65. Top Insulation Assembly (Item 58)

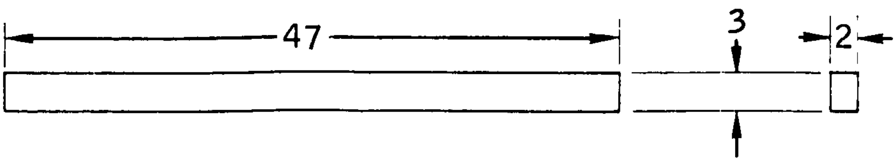


Figure 66. Top Insulation Spacer (Item 59, 60)

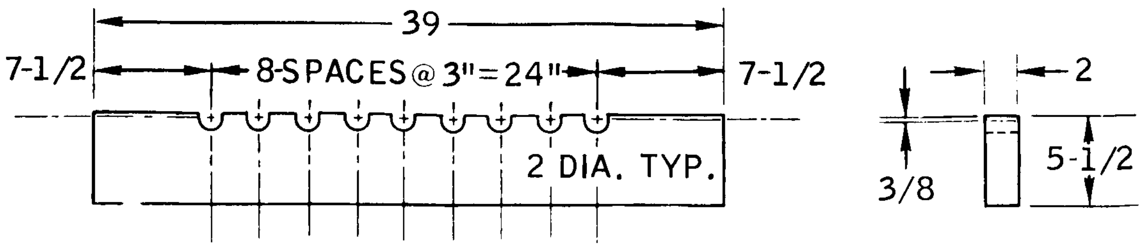


Figure 67. End Enclosure Insulation (Item 49)

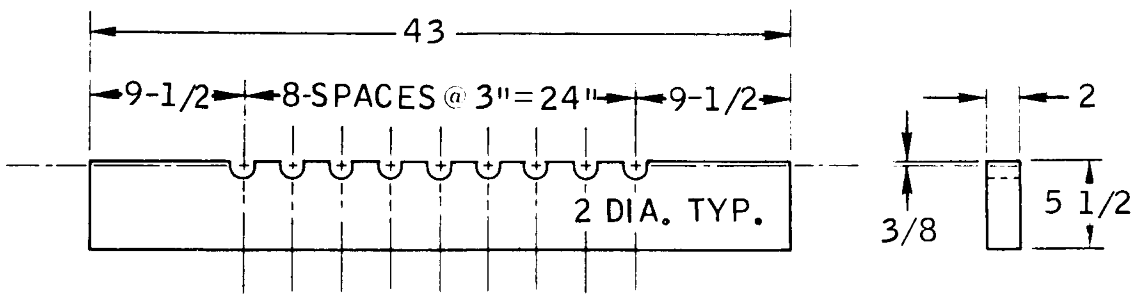


Figure 68. End Enclosure Filler (Item 48)

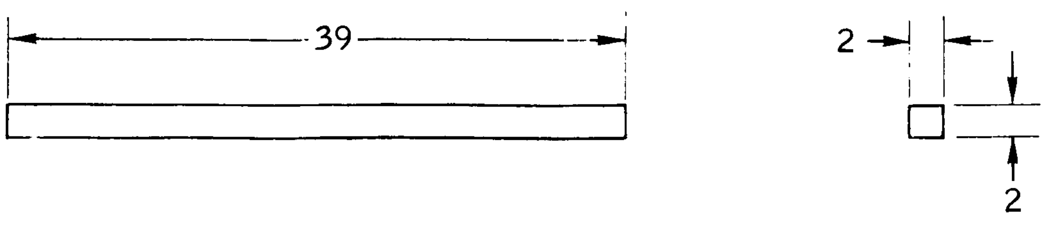


Figure 69. End Enclosure (Item 62)

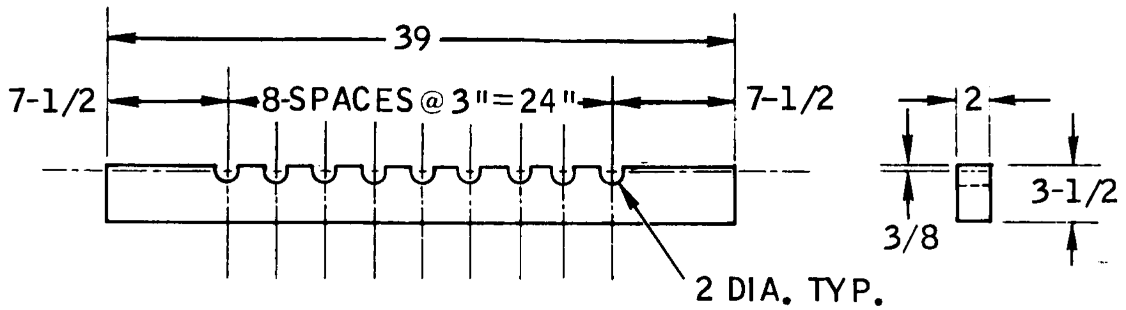


Figure 70. Removable End Insulation & Filler (Item 63, 64)

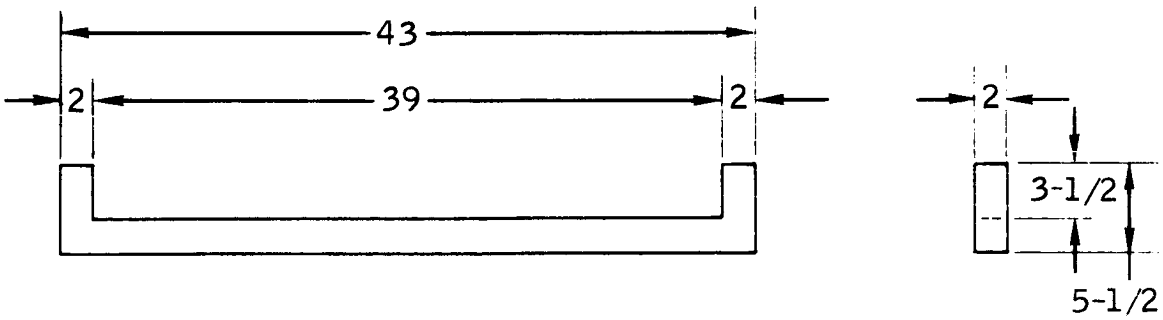


Figure 71. Fixed End Filler (Item 47)

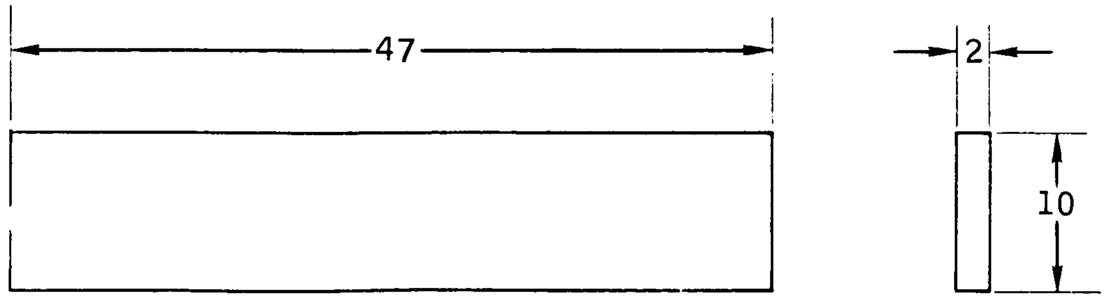


Figure 72. Access Cover Top Filler (Item 66, 75)*

*See also Section B.

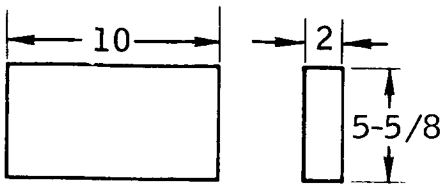


Figure 73. Access Cover Corner Insulation (Item 69, 70, 78, 79)

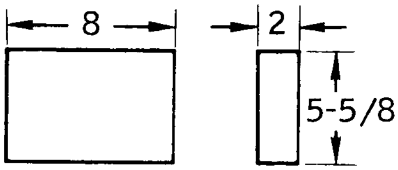


Figure 74. Access Cover Side Insulation (Item 72, 73, 81. 82)

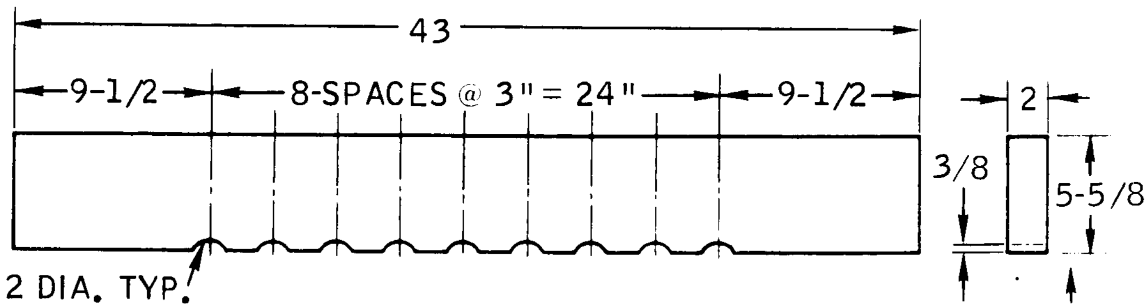


Figure 75. Access Cover End Filler (Item 68, 77) *

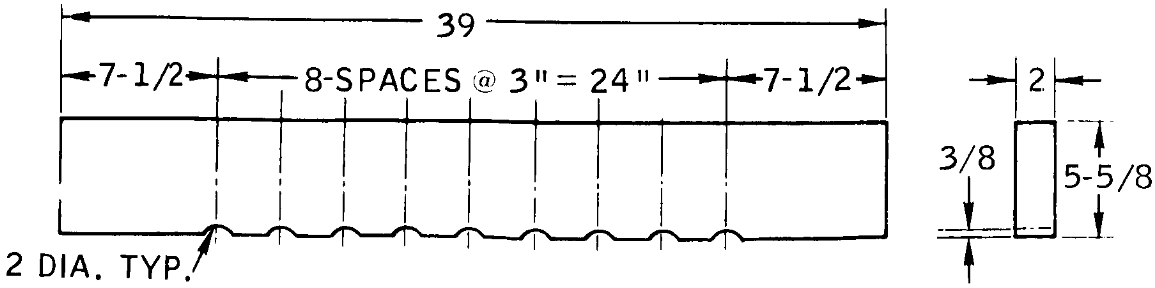


Figure 76. Access Cover End Insulation (Item 71, 80)*

*See also Section B.

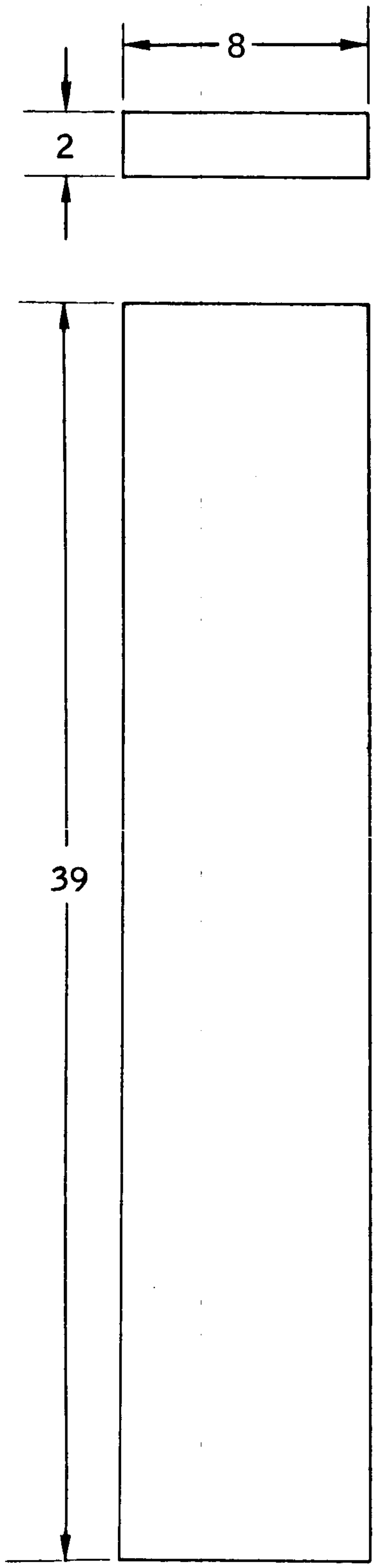
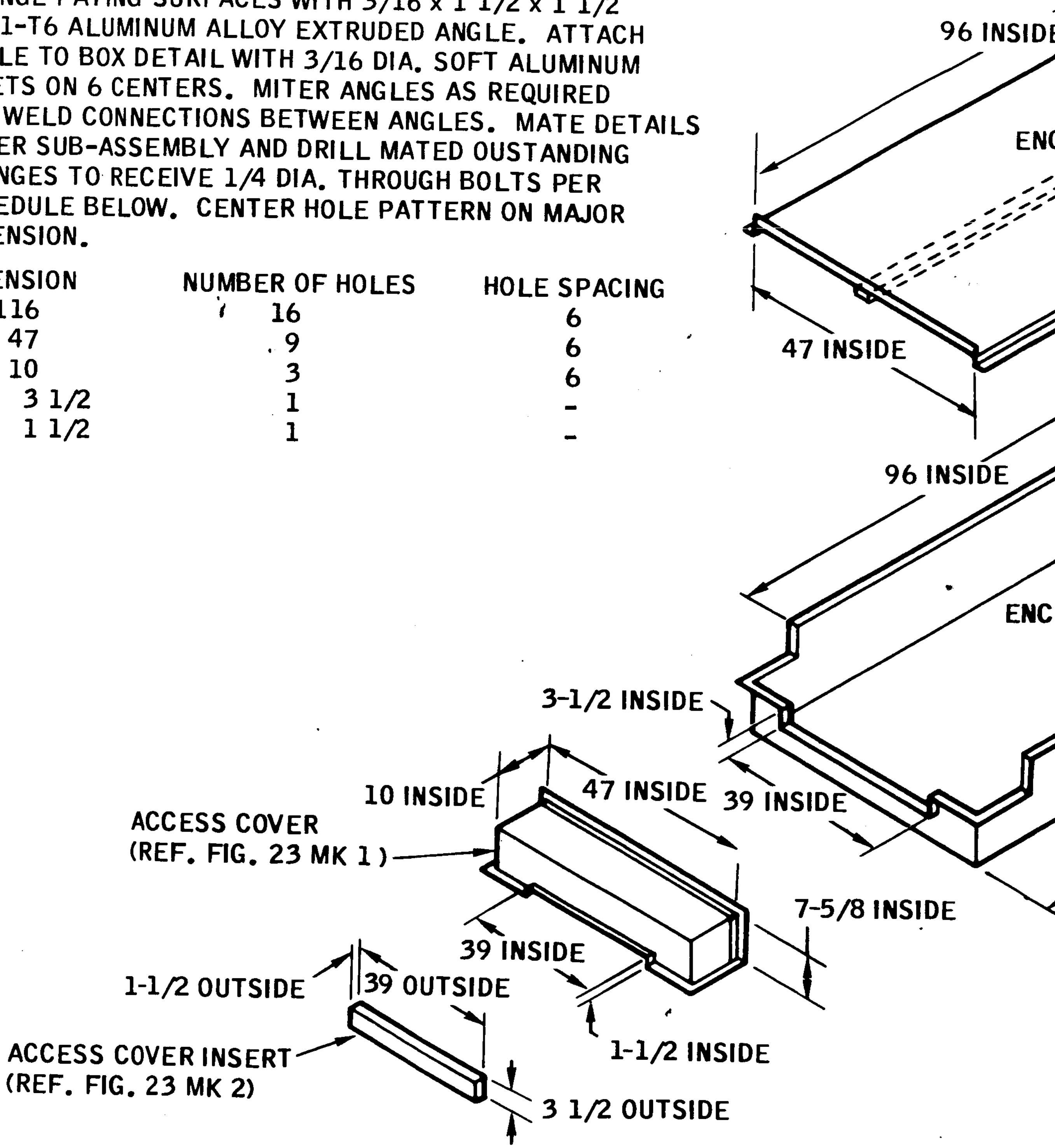


Figure 77. Access Cover Top Insulation (Item 67, 76)

NOTE:

MAKE FROM 6061-T6 ALUMINUM ALLOY. WELD ALL BOX DETAIL AT CORNERS AND FLANGE FAYING SURFACES WITH 3/16 x 1 1/2 x 1 1/2 6061-T6 ALUMINUM ALLOY EXTRUDED ANGLE. ATTACH ANGLE TO BOX DETAIL WITH 3/16 DIA. SOFT ALUMINUM RIVETS ON 6 CENTERS. MITER ANGLES AS REQUIRED AND WELD CONNECTIONS BETWEEN ANGLES. MATE DETAILS AFTER SUB-ASSEMBLY AND DRILL MATED OUSTANDING FLANGES TO RECEIVE 1/4 DIA. THROUGH BOLTS PER SCHEDULE BELOW. CENTER HOLE PATTERN ON MAJOR DIMENSION.

DIMENSION	NUMBER OF HOLES	HOLE SPACING
116	16	6
47	9	6
10	3	6
3 1/2	1	-
1 1/2	1	-



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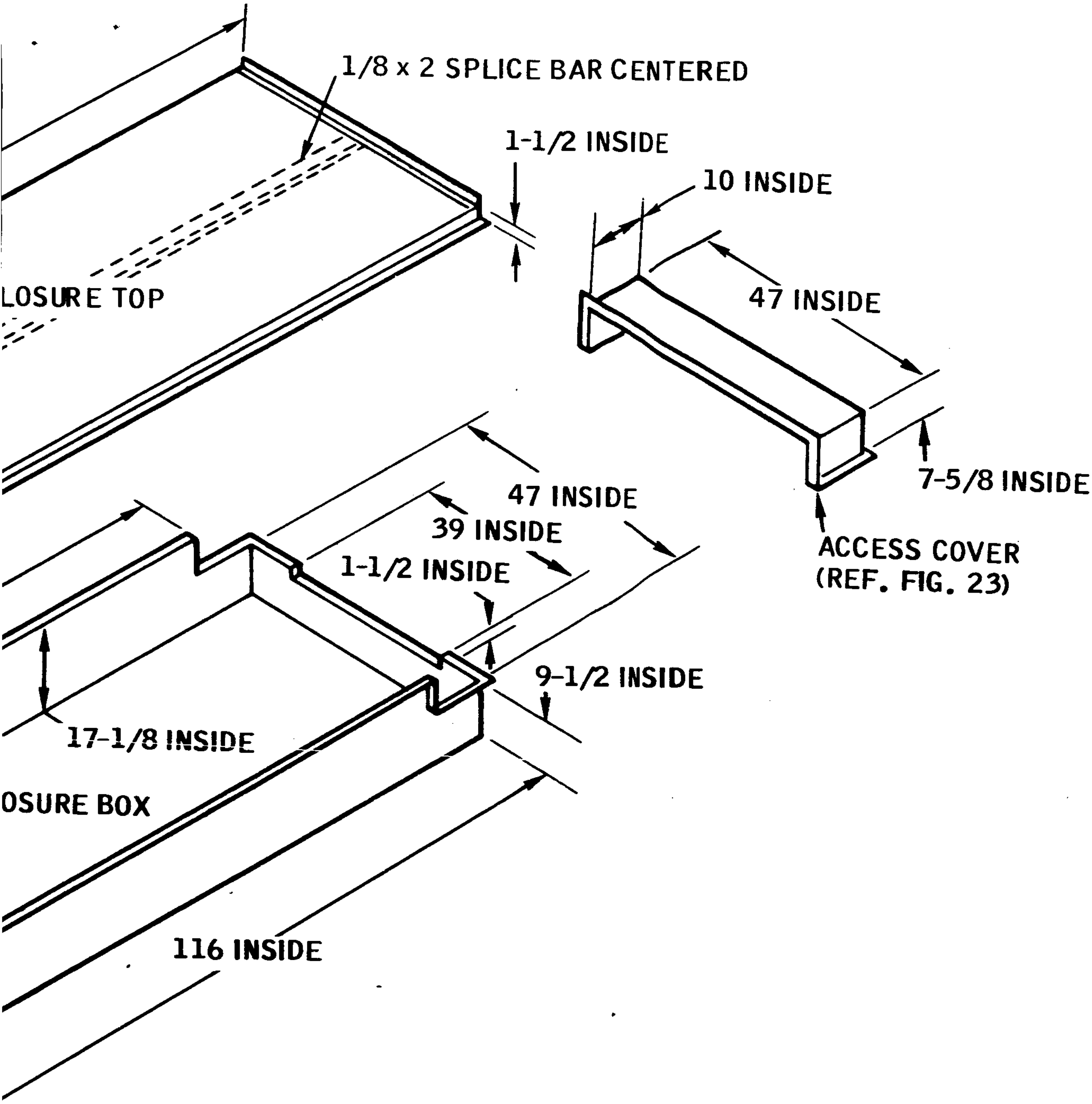

Figure 78. Aluminum Alloy Enclosure Box

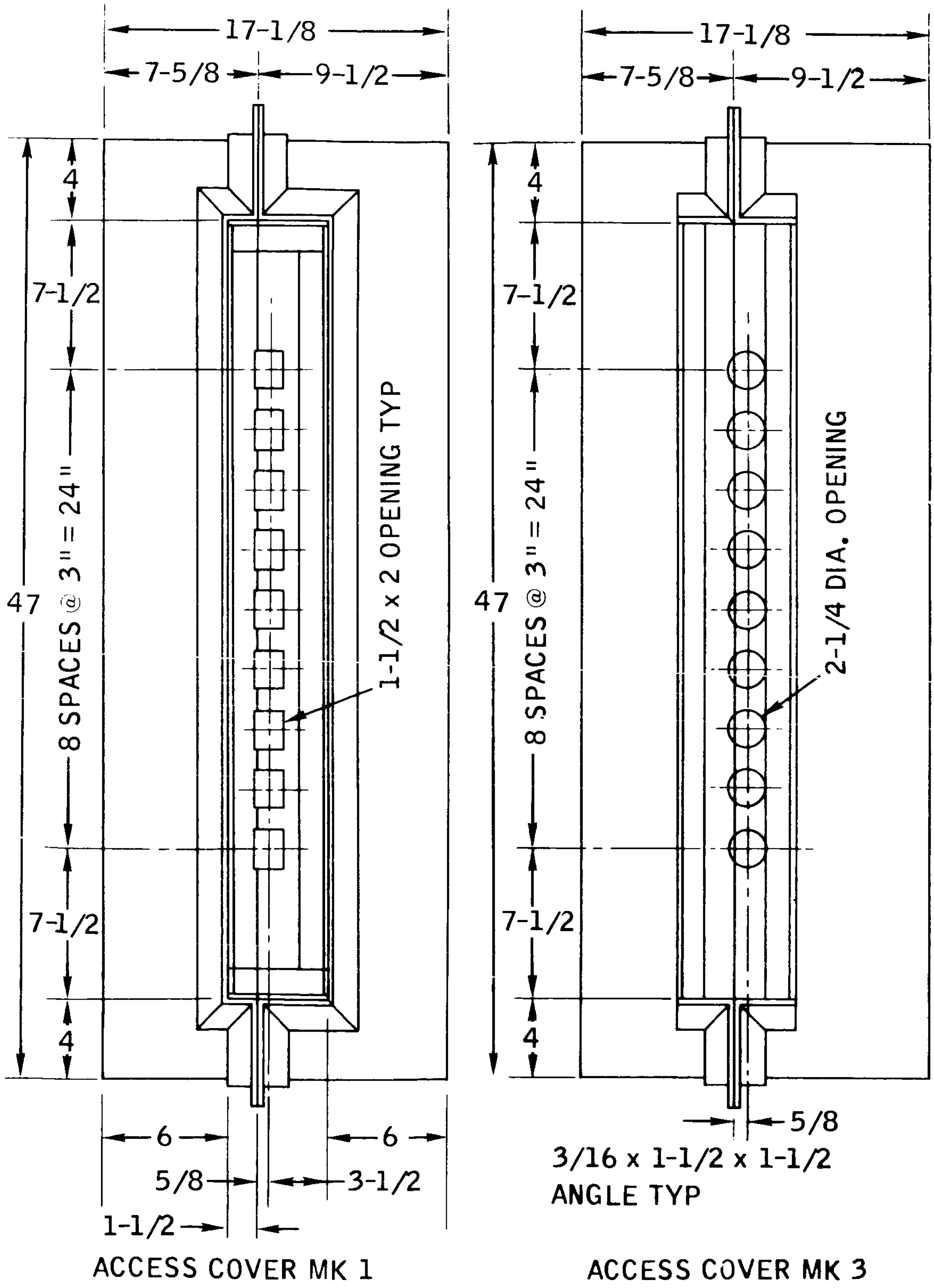

Figure 79. Enclosure Box End Detail

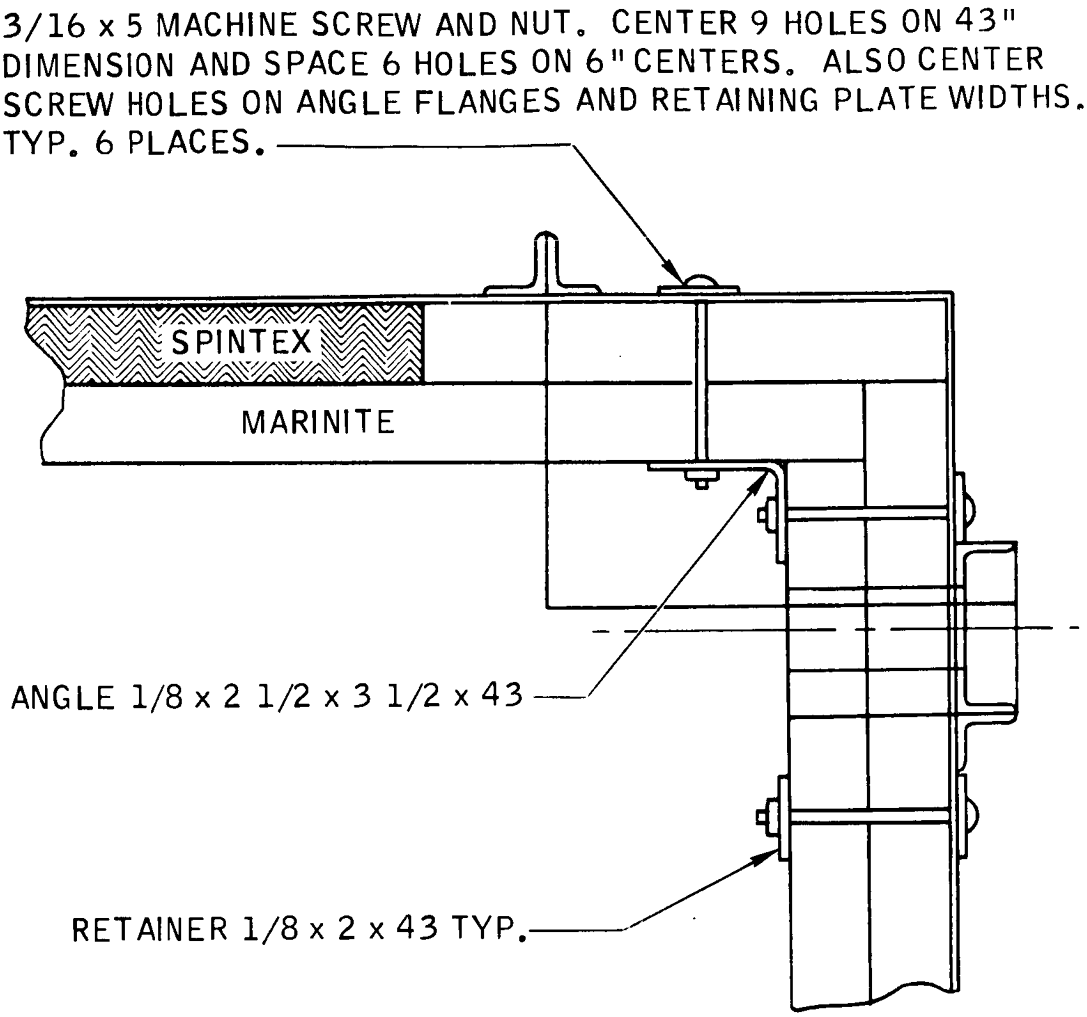

Figure 80. Insulation Retaining Detail

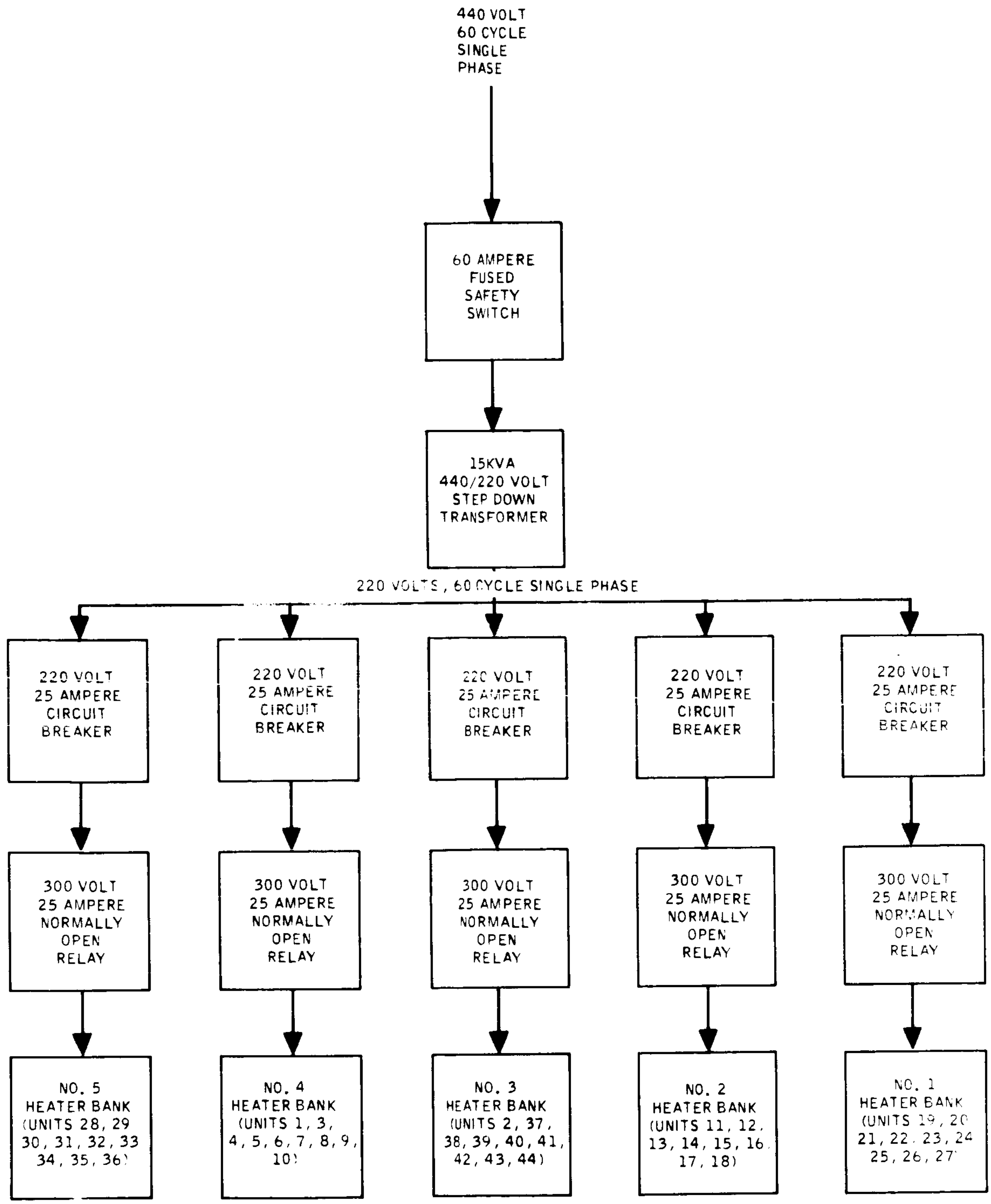

Figure 81. Heat Source Electrical Connections (Schematic)

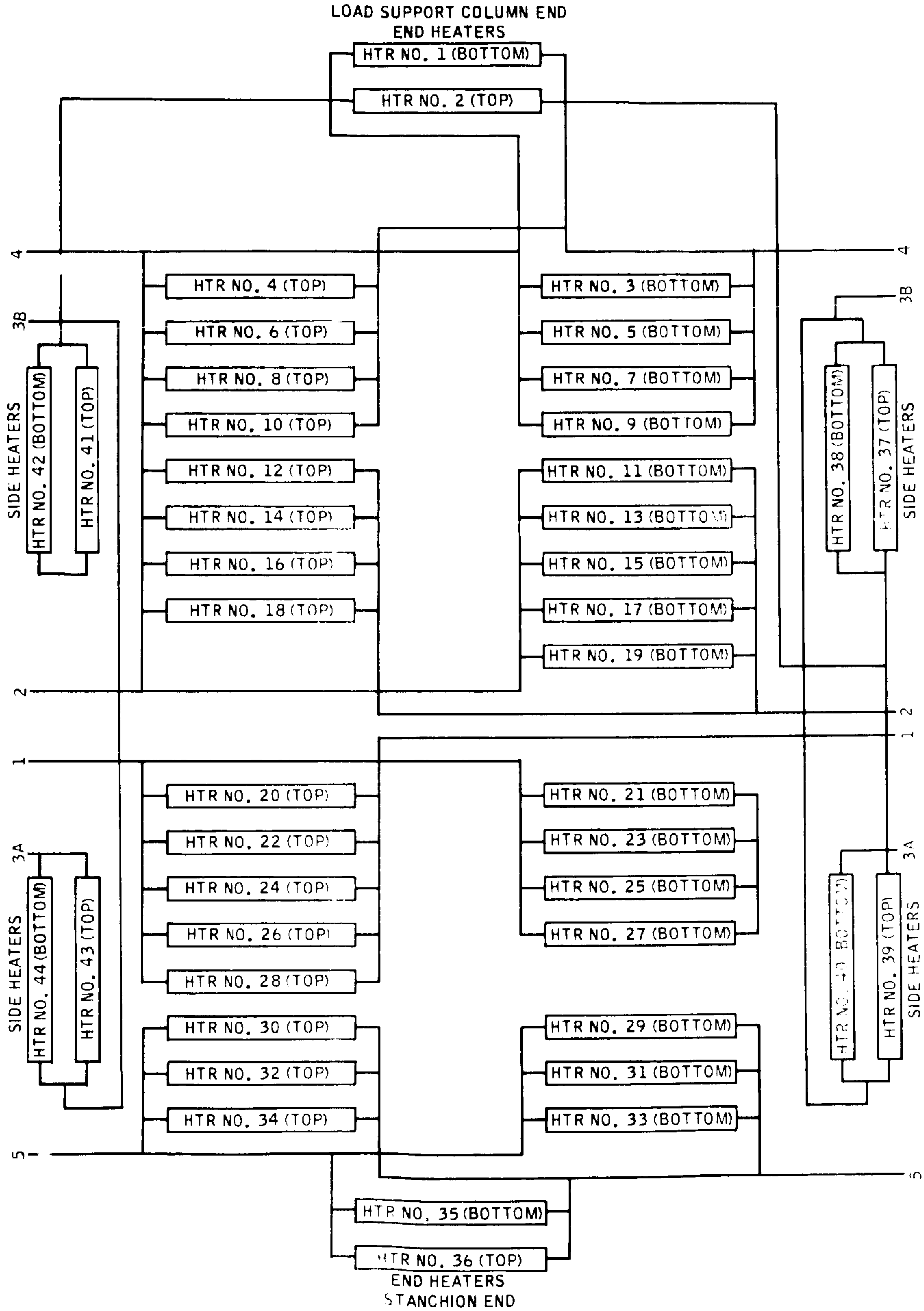

Figure 82. Heating Platten Internal Wiring (Schematic)

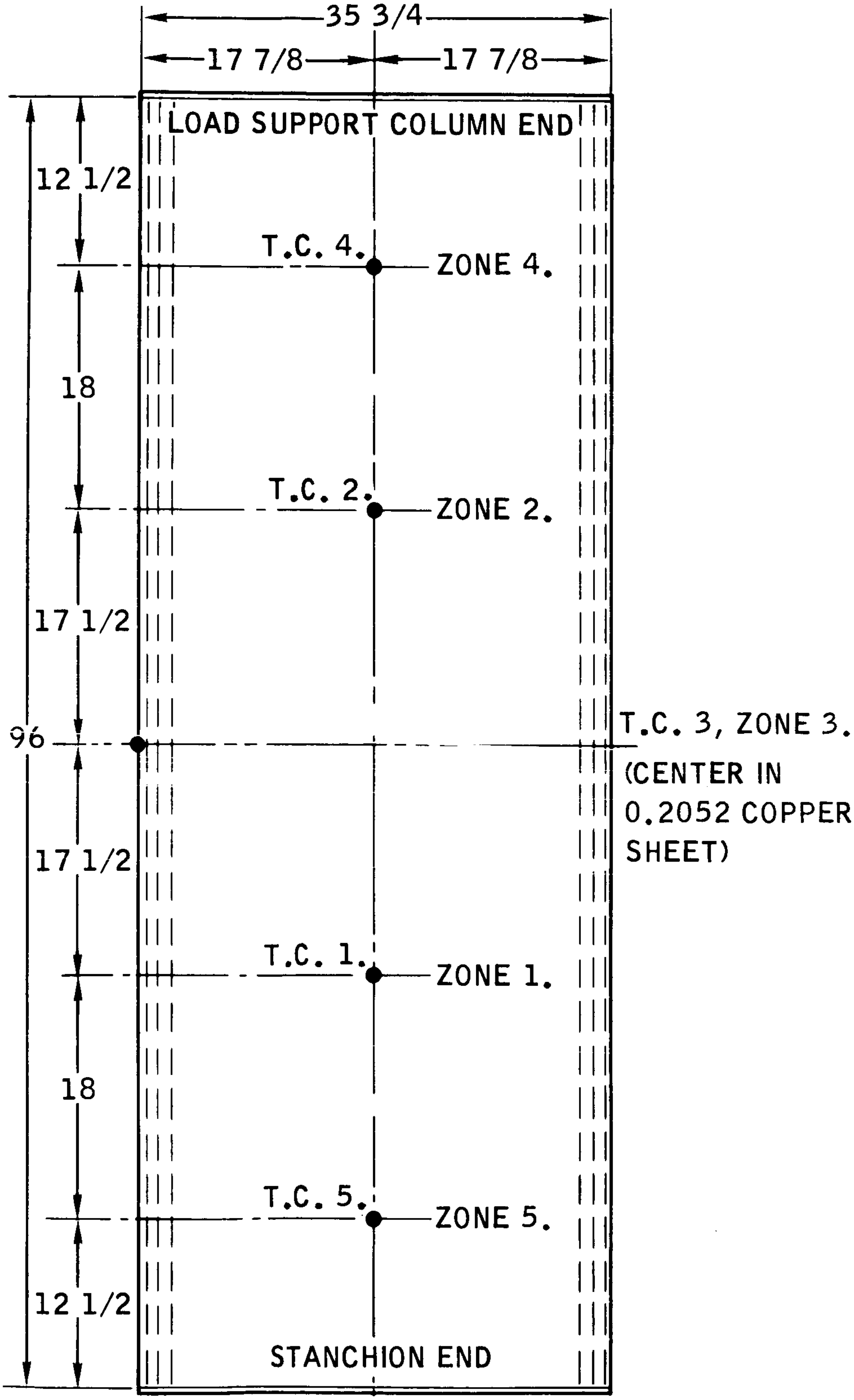

Figure 83. Heating Platten Unit Temperature Control Thermocouple Array

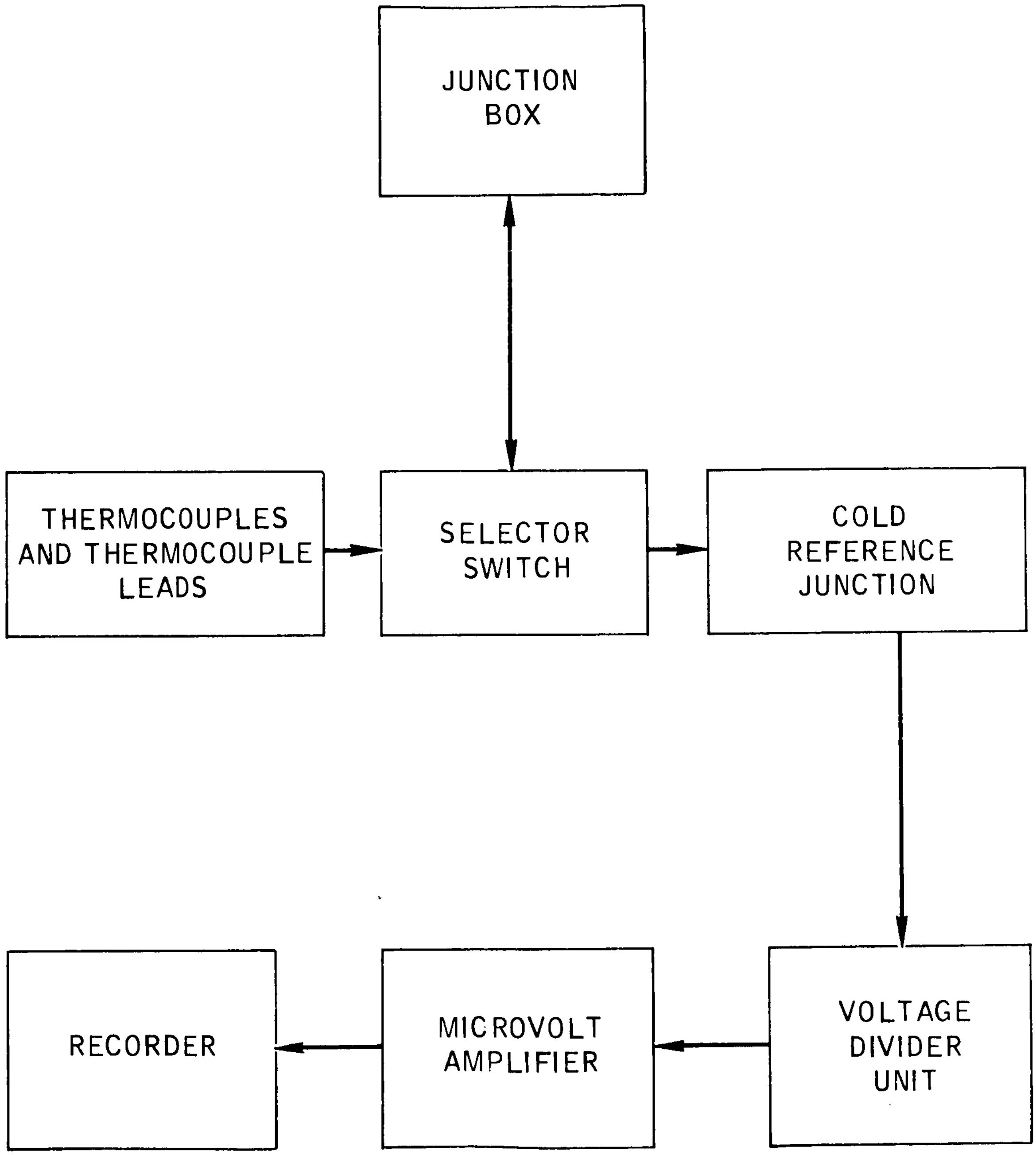

Figure 84. Specimen Temperature Indication System Block Diagram

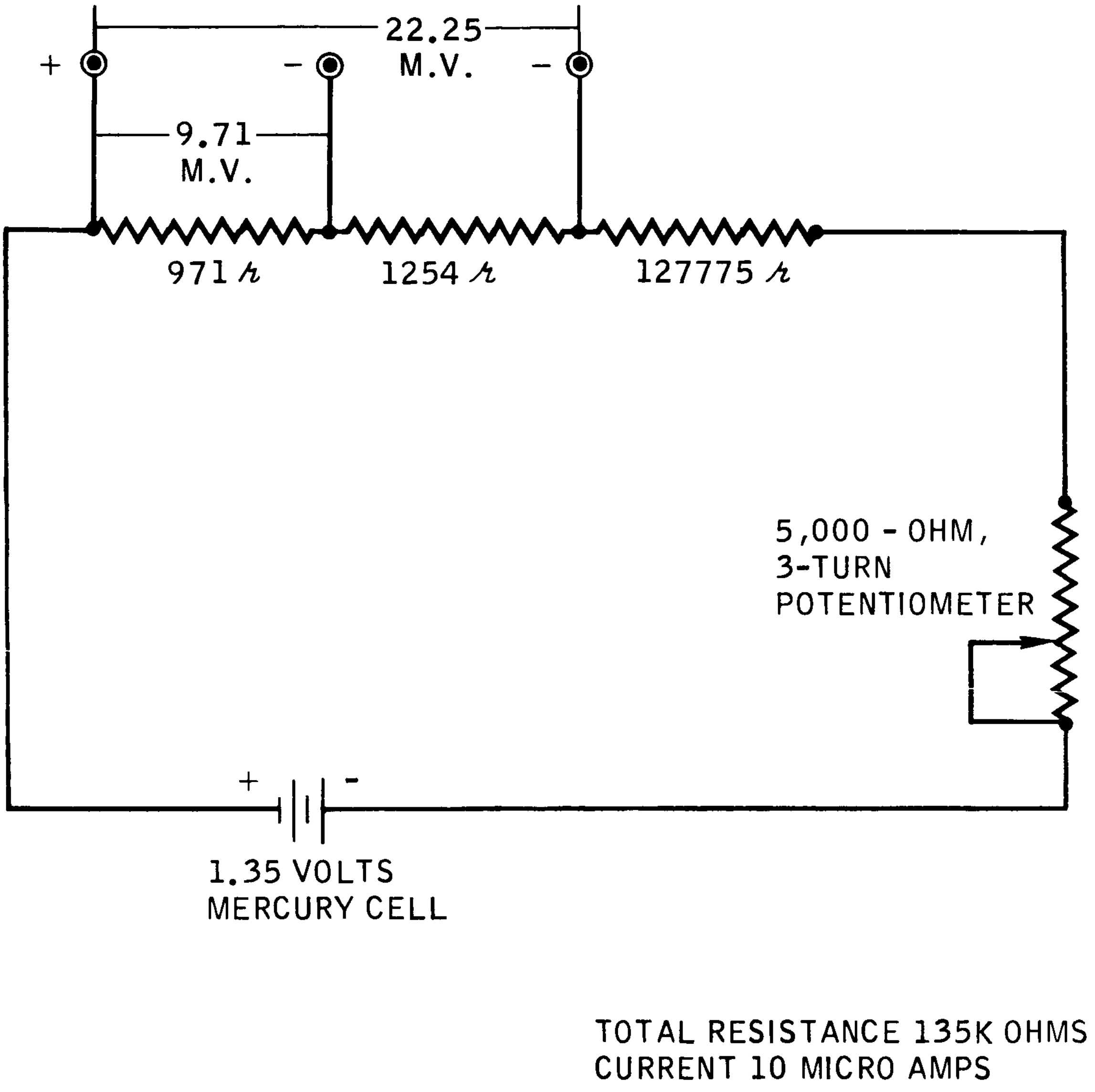

Figure 85. Voltage Divider Unit Schematic Circuit Diagram

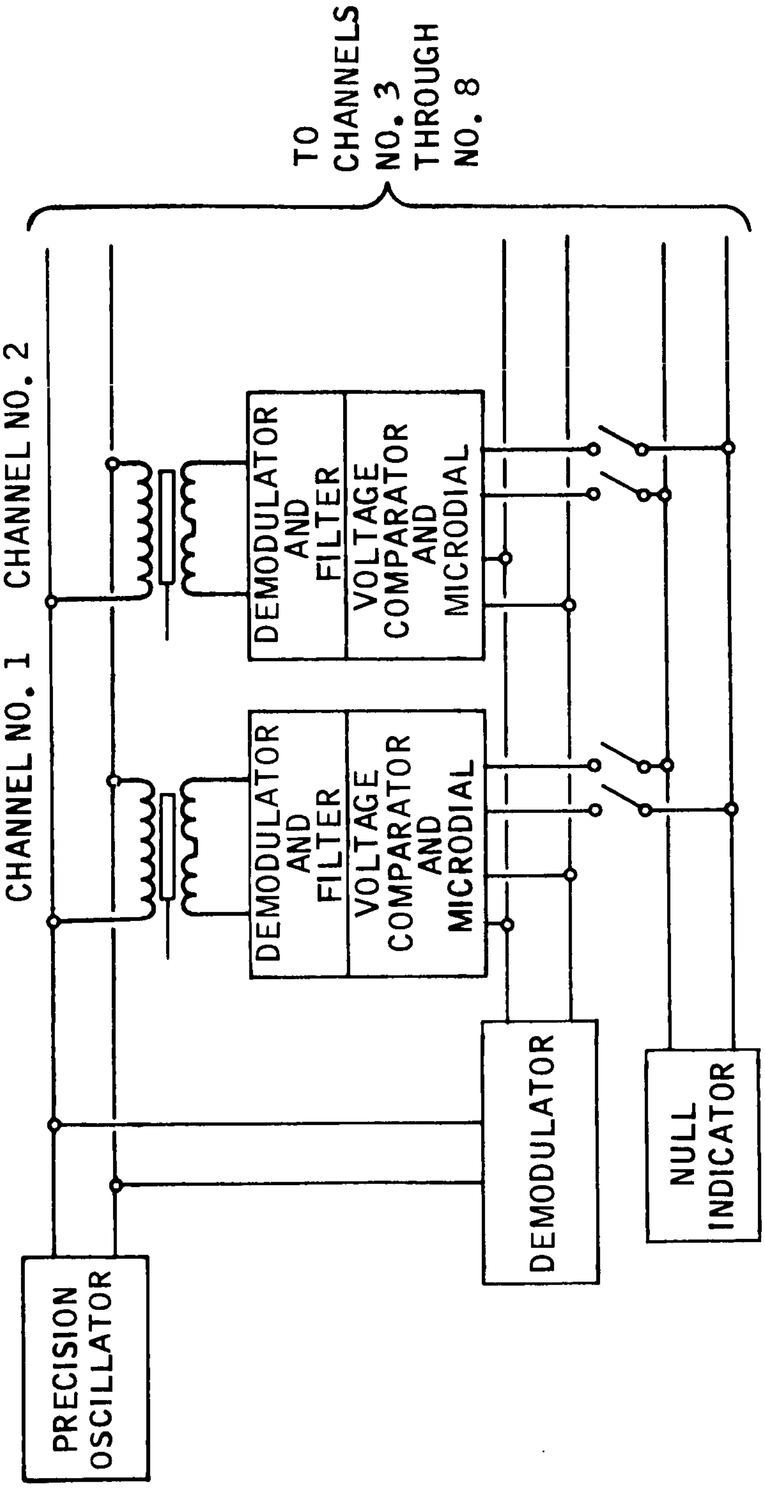

Figure 86. Creep Measurement System Arrangement - Schematic

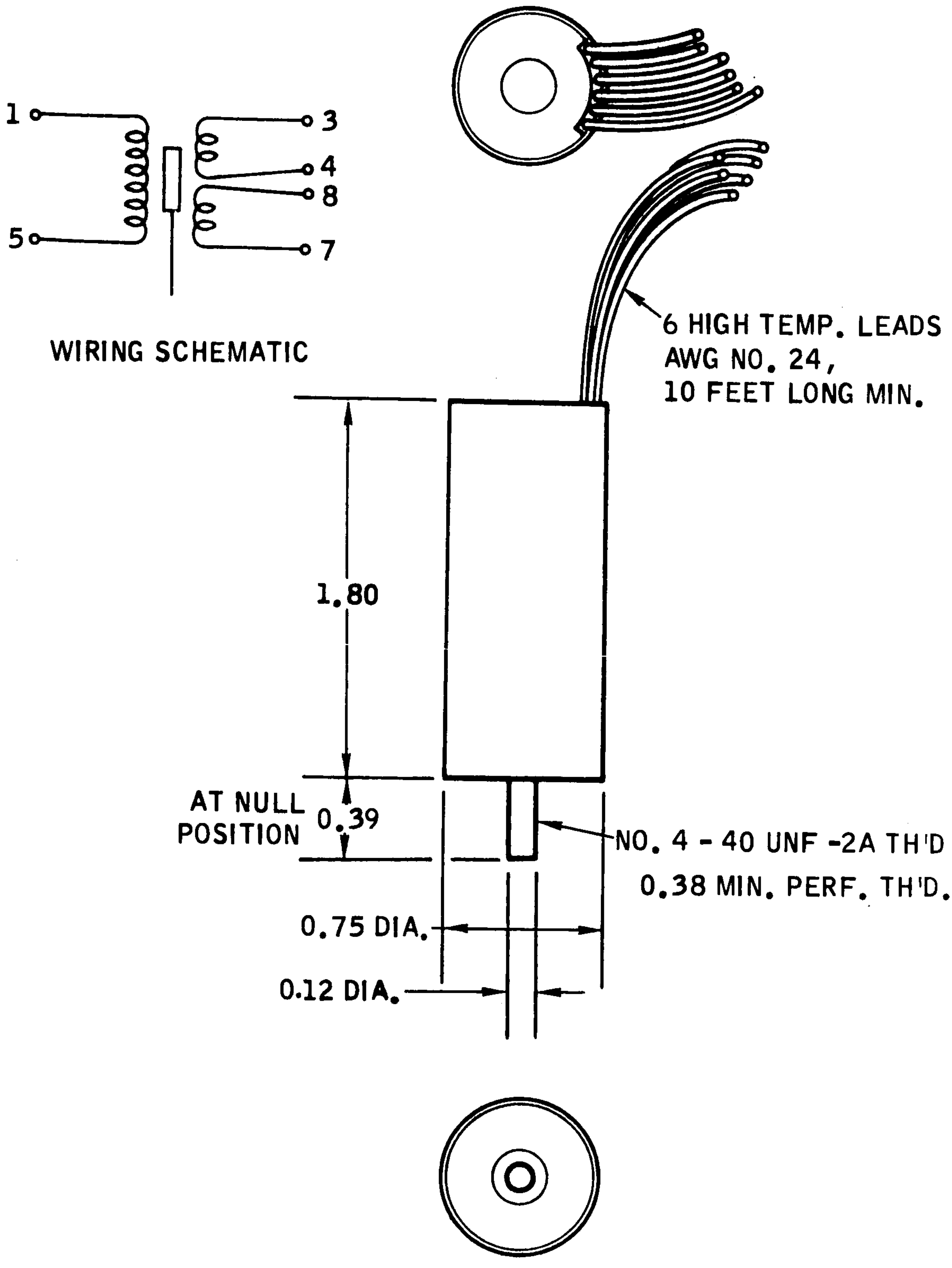

Figure 87. Linear Transducer

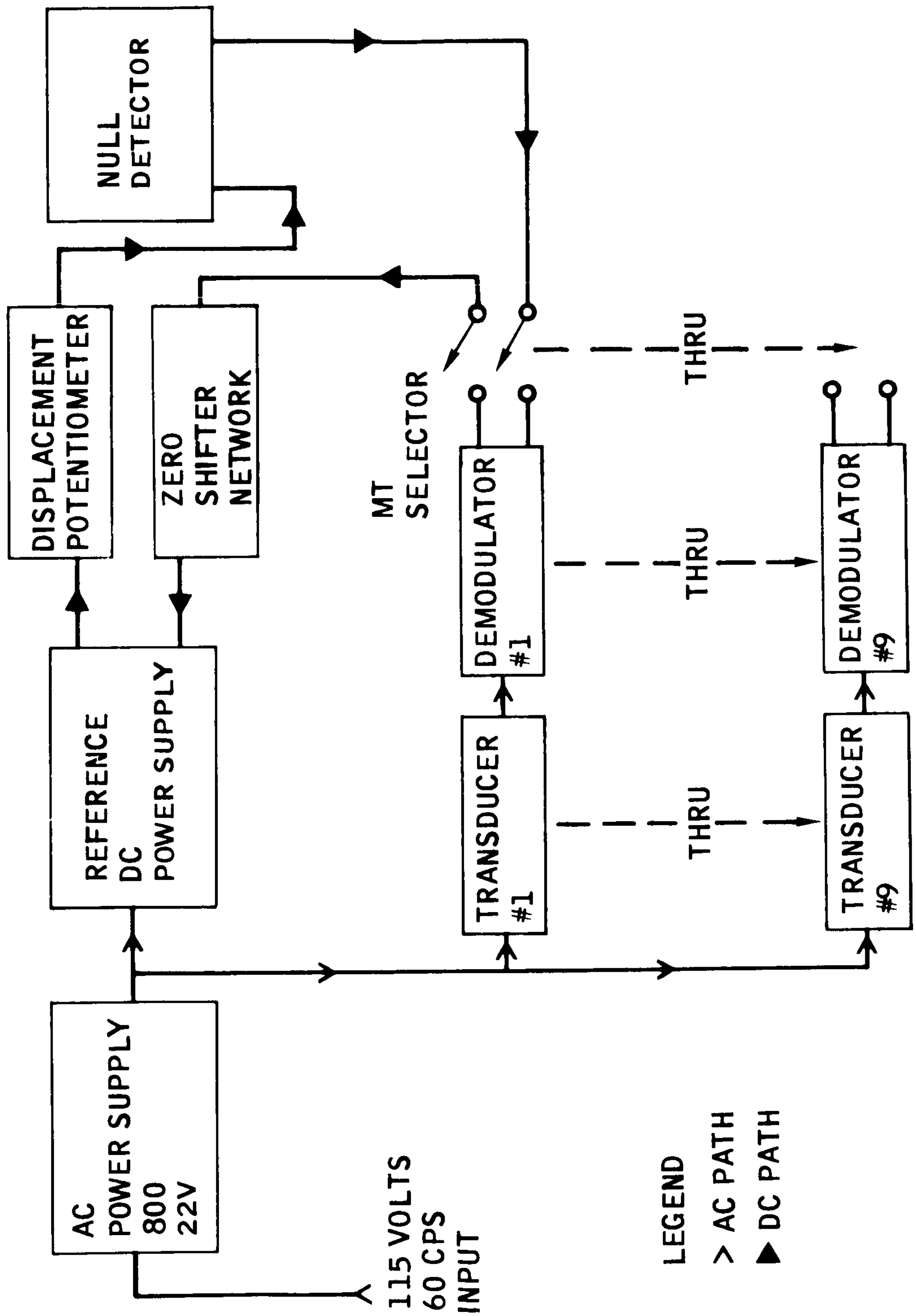

Figure 88. Linear Displacement Indicator (Block Diagram)

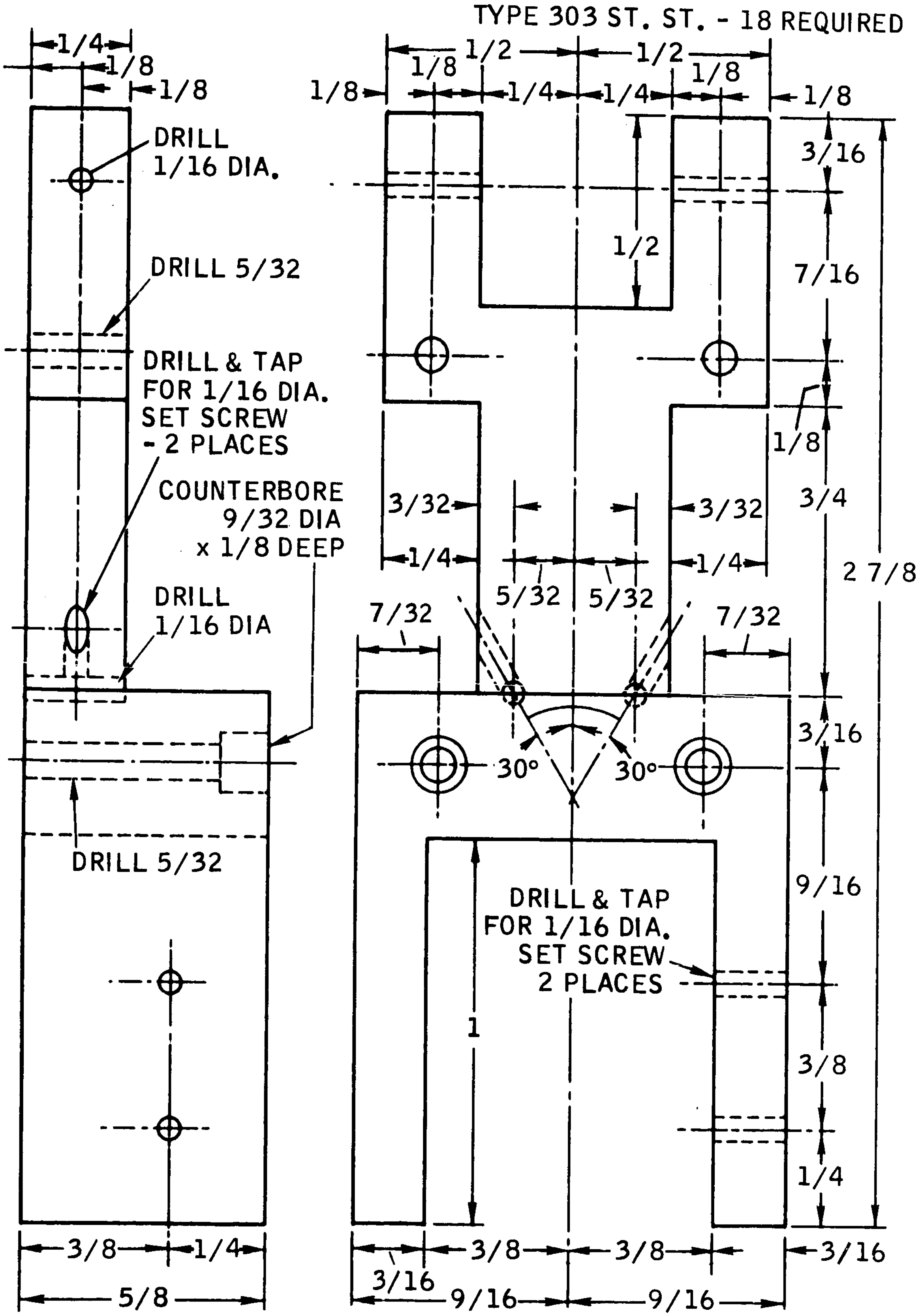

Figure 89. Transducer Holder*

*See Also Section 2.

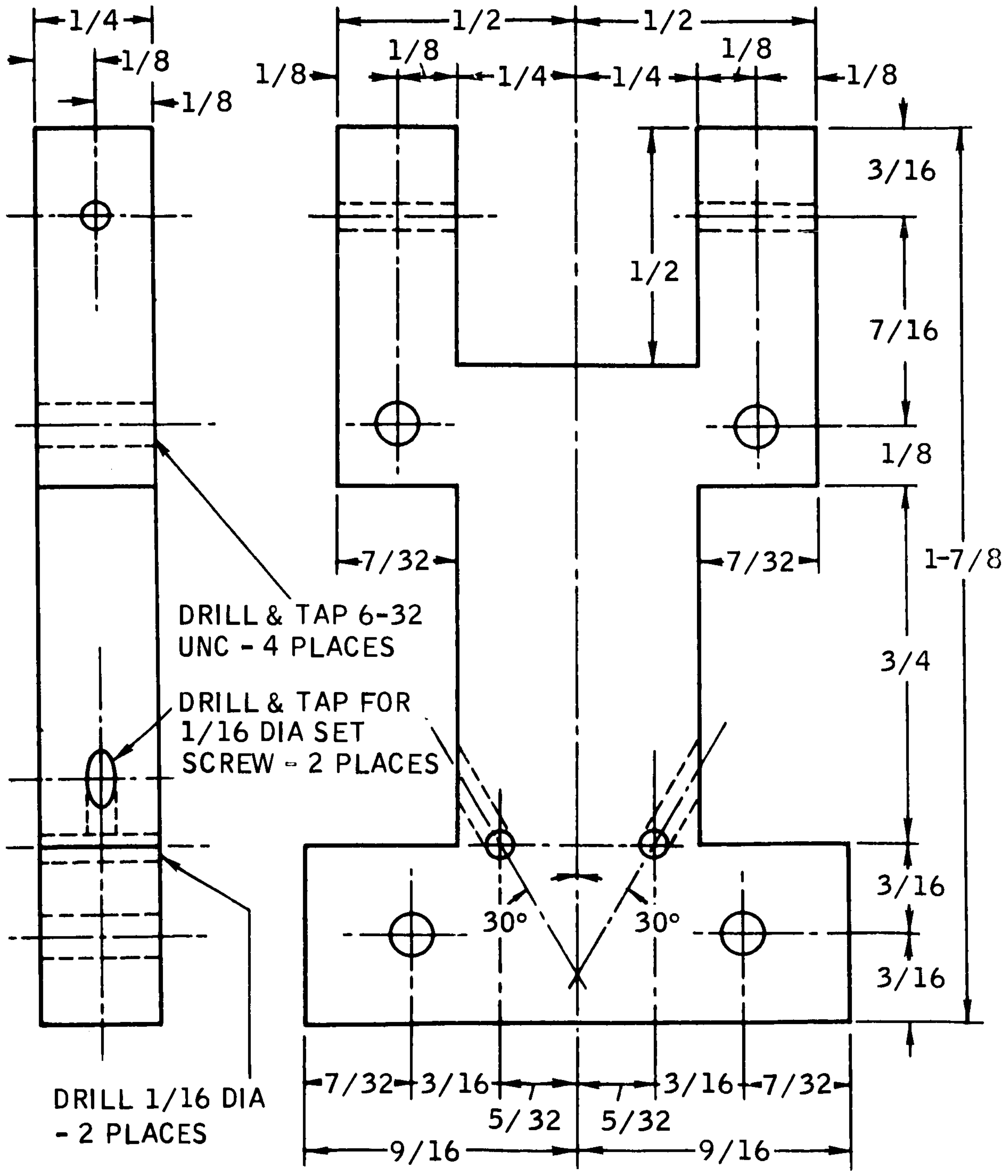

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Figure 90. Transducer Holder Clamp

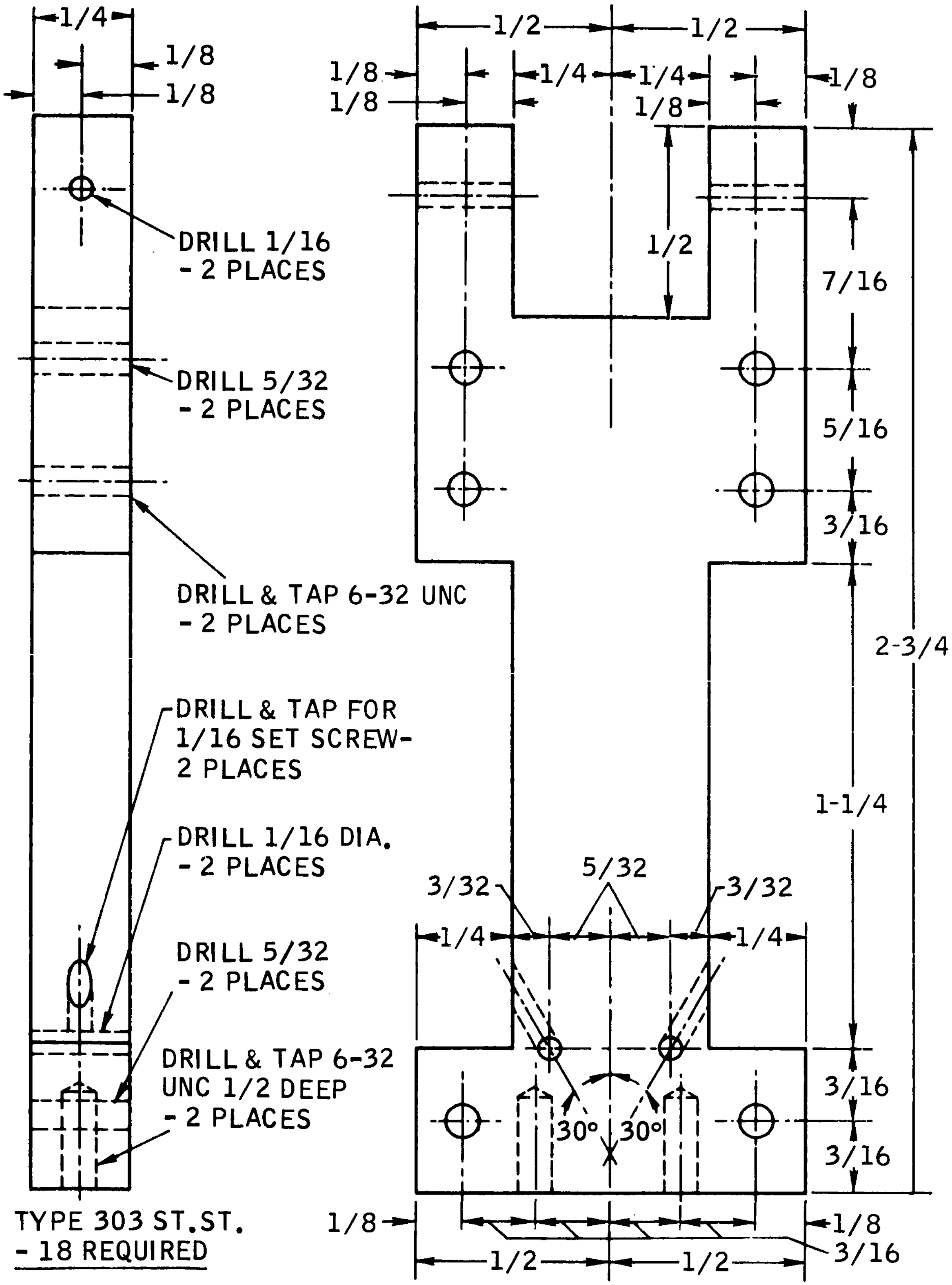


Figure 91. Adjustment Fixture Body

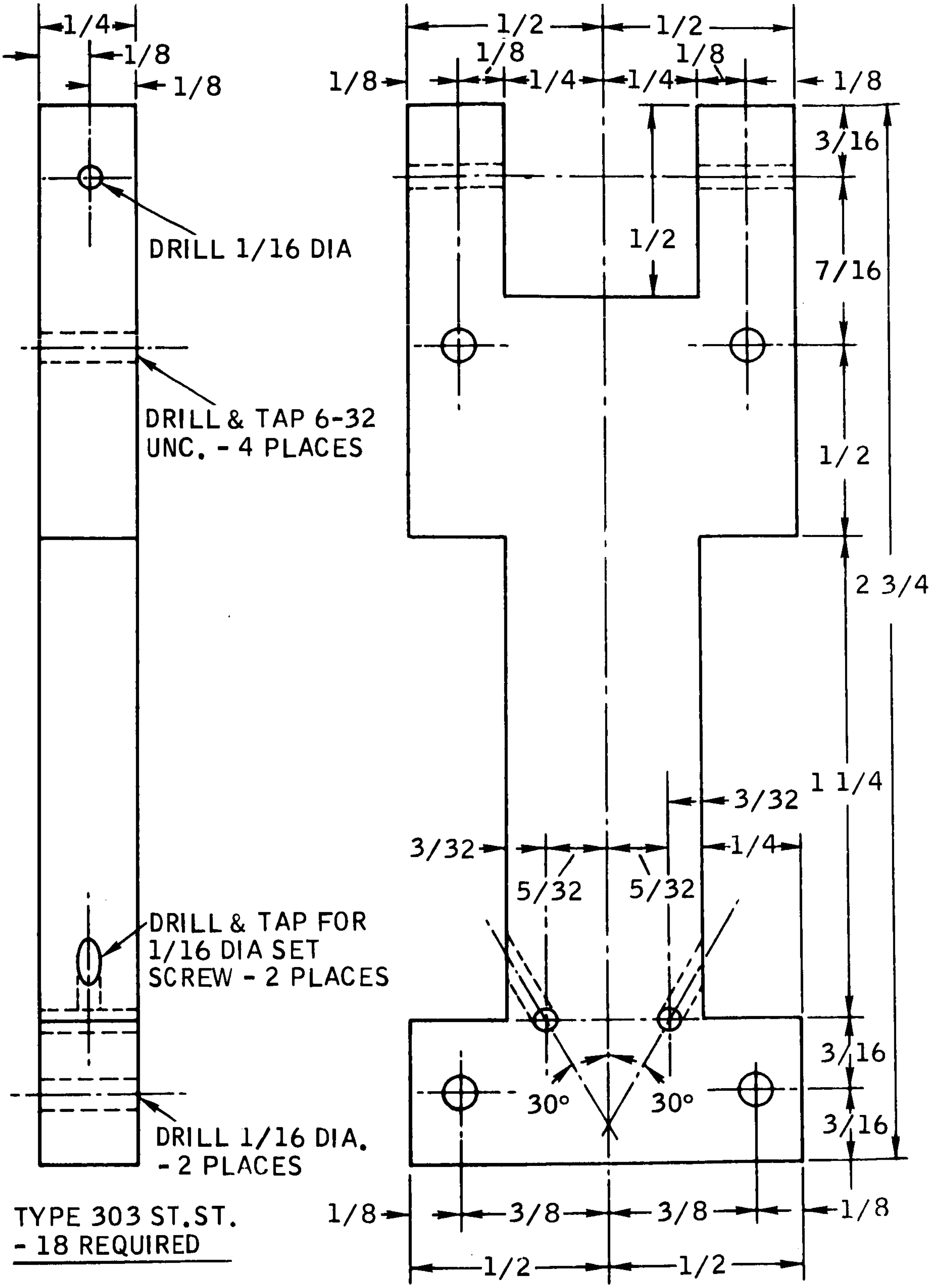


Figure 92. Adjustment Fixture Clamp

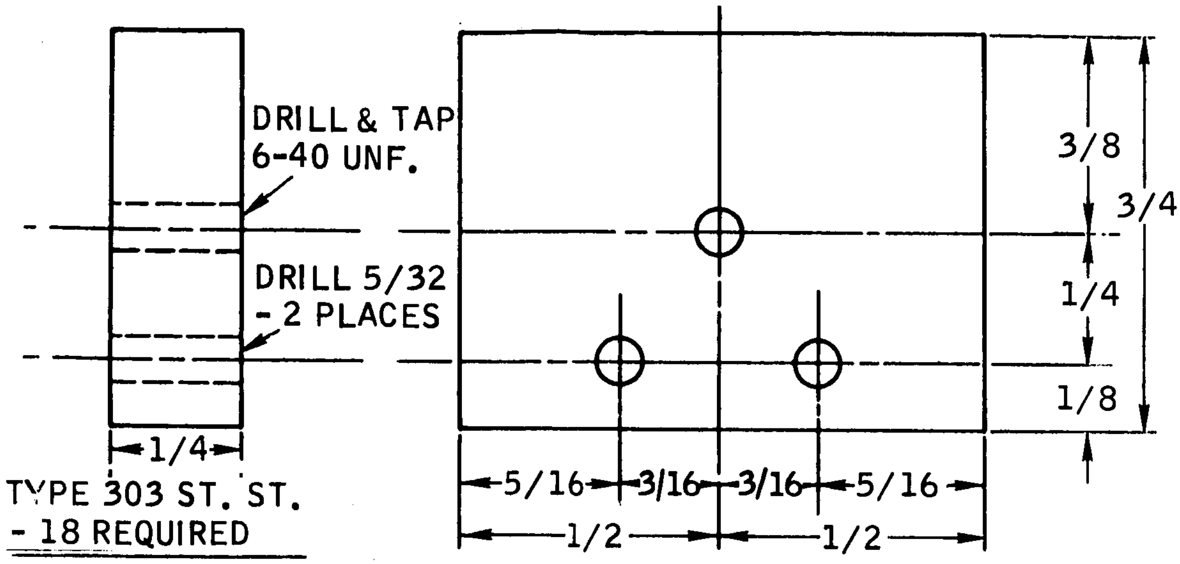


Figure 93. Adjustment Fixture Screw Holder

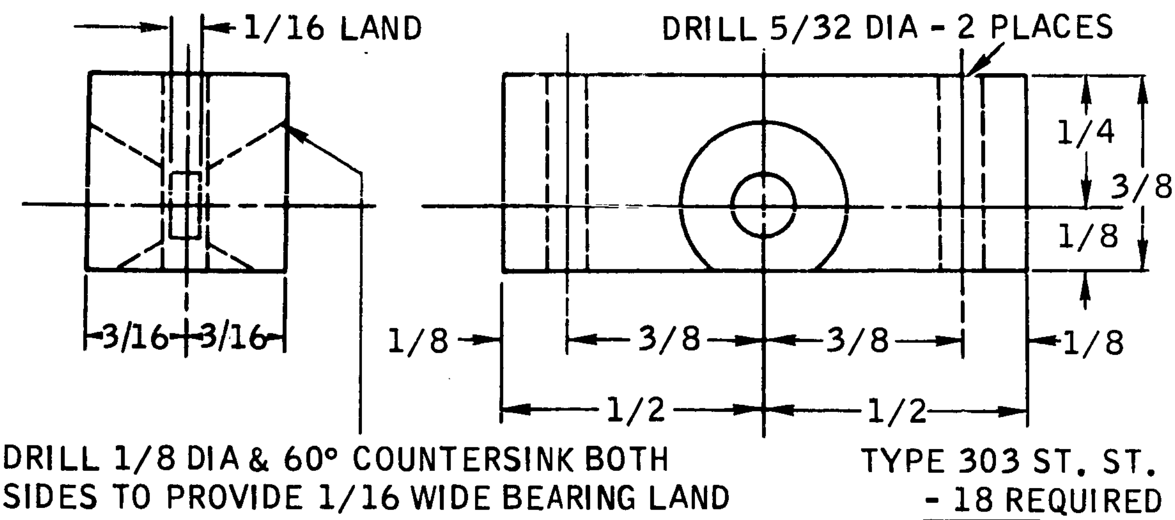


Figure 94. Adjustment Fixture Push Rod Guide

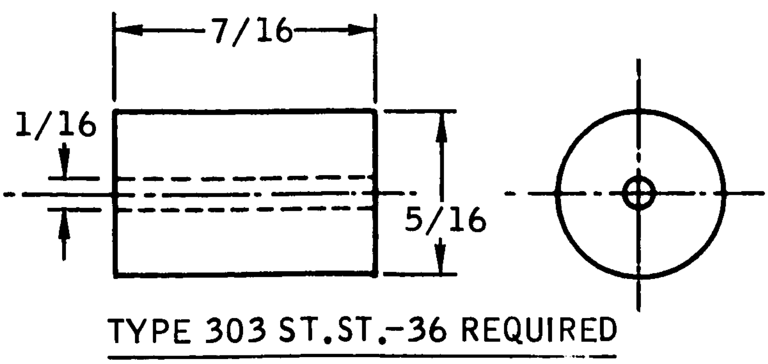


Figure 95. Transducer Holder and Adjustment Fixture Roller

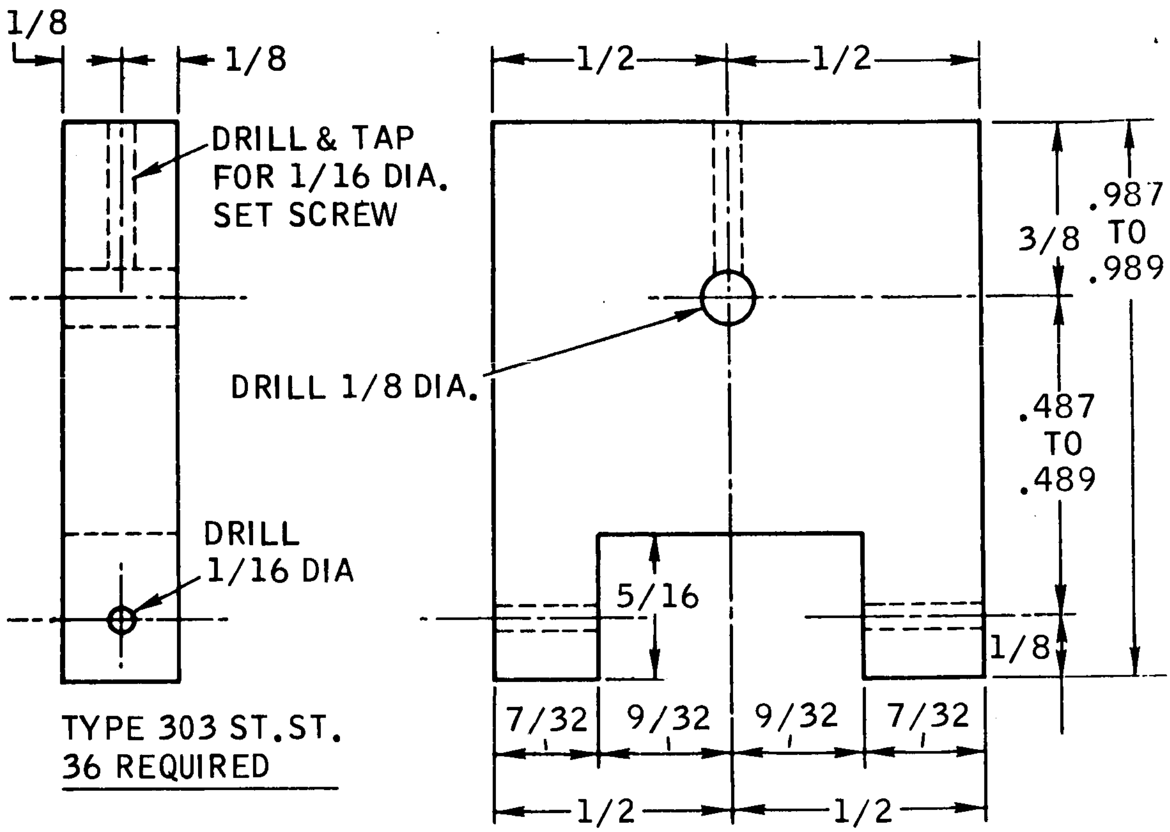


Figure 96. Push Rod Support

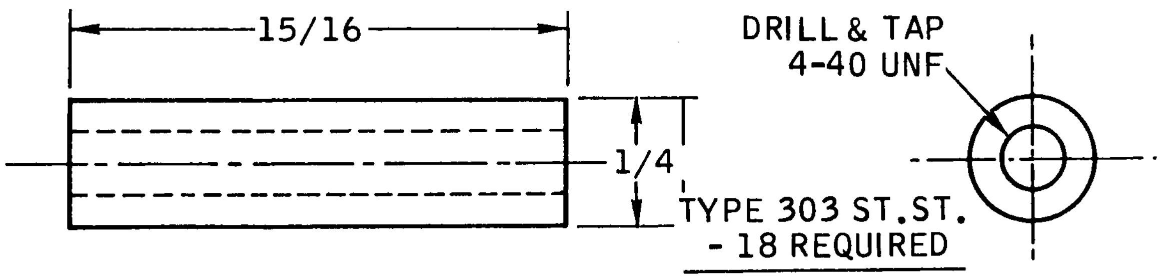


Figure 97. Push Rod Coupling

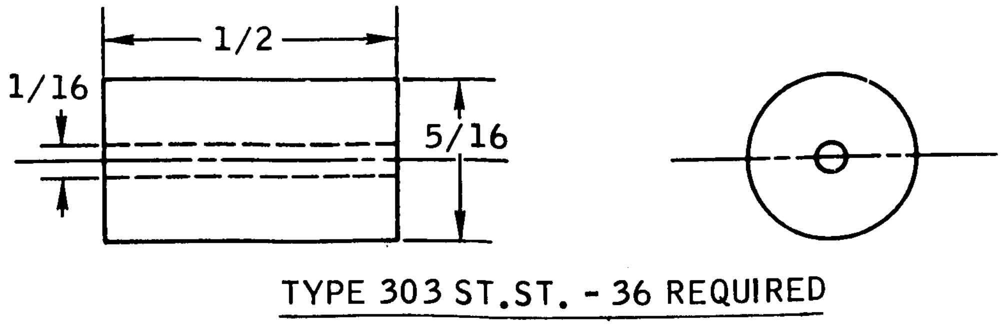


Figure 98. Push Rod Support Roller

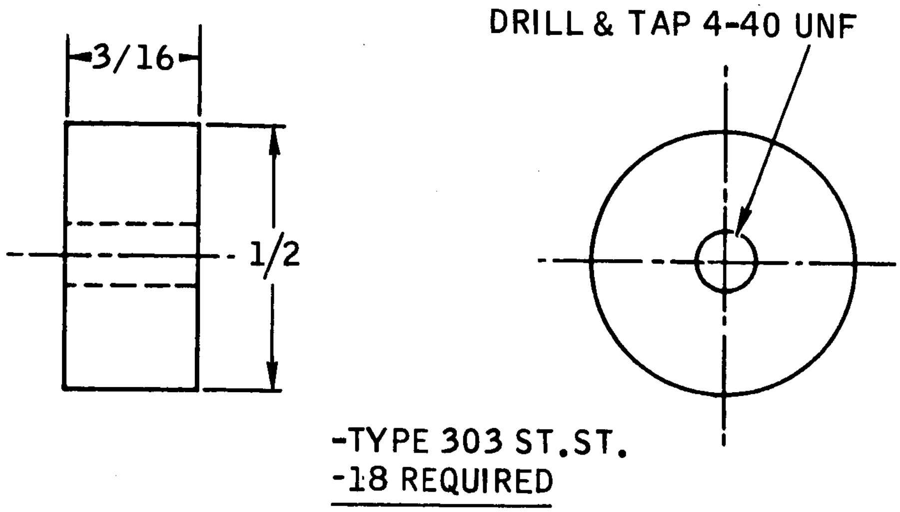


Figure 99. Push Rod Bearing Piece

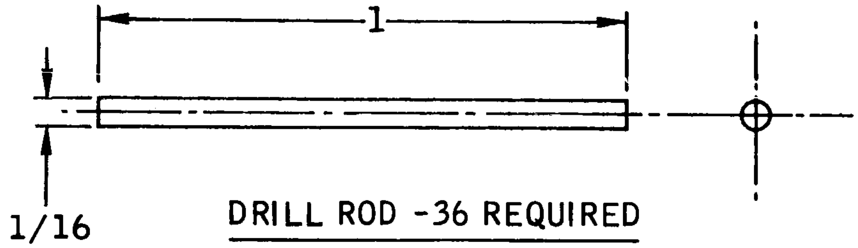


Figure 100. Push Rod Support Pin

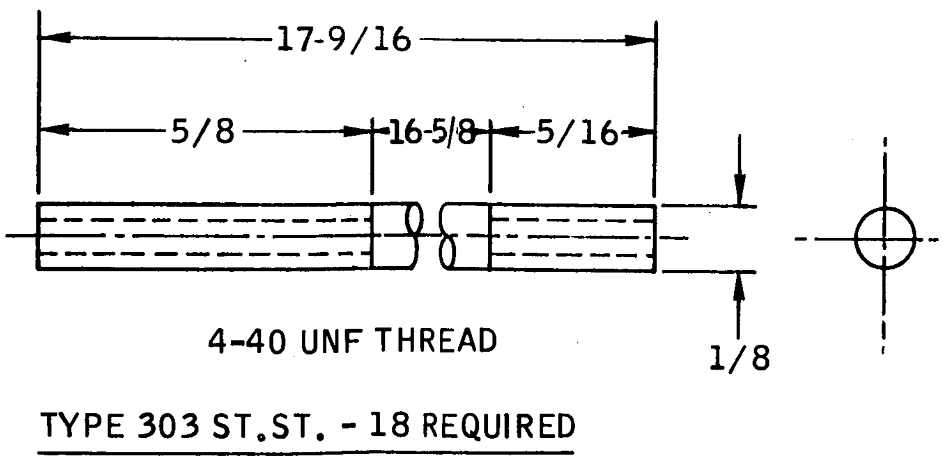


Figure 101. Push Rod

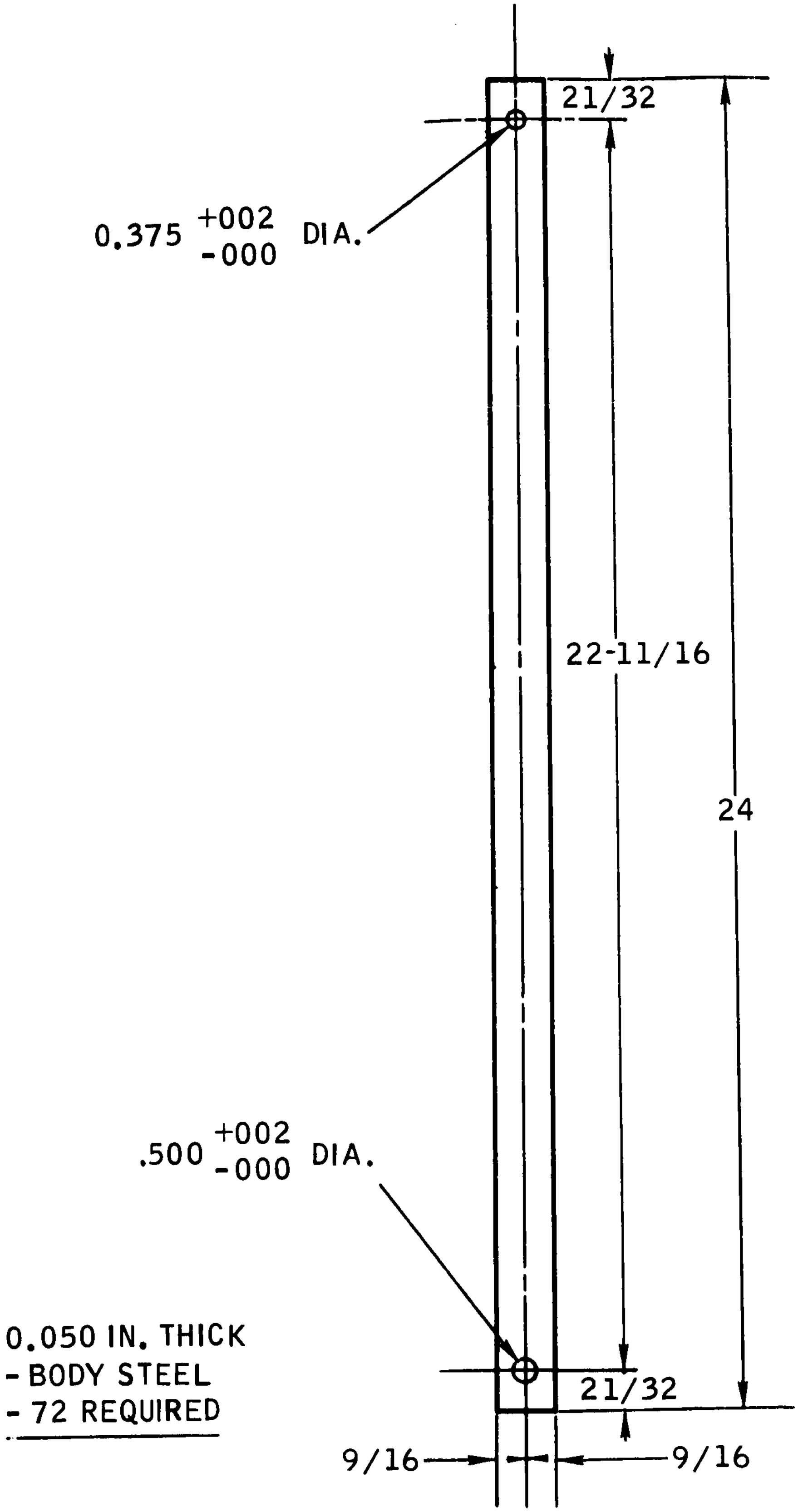


Figure 102. Specimen Attach Strap

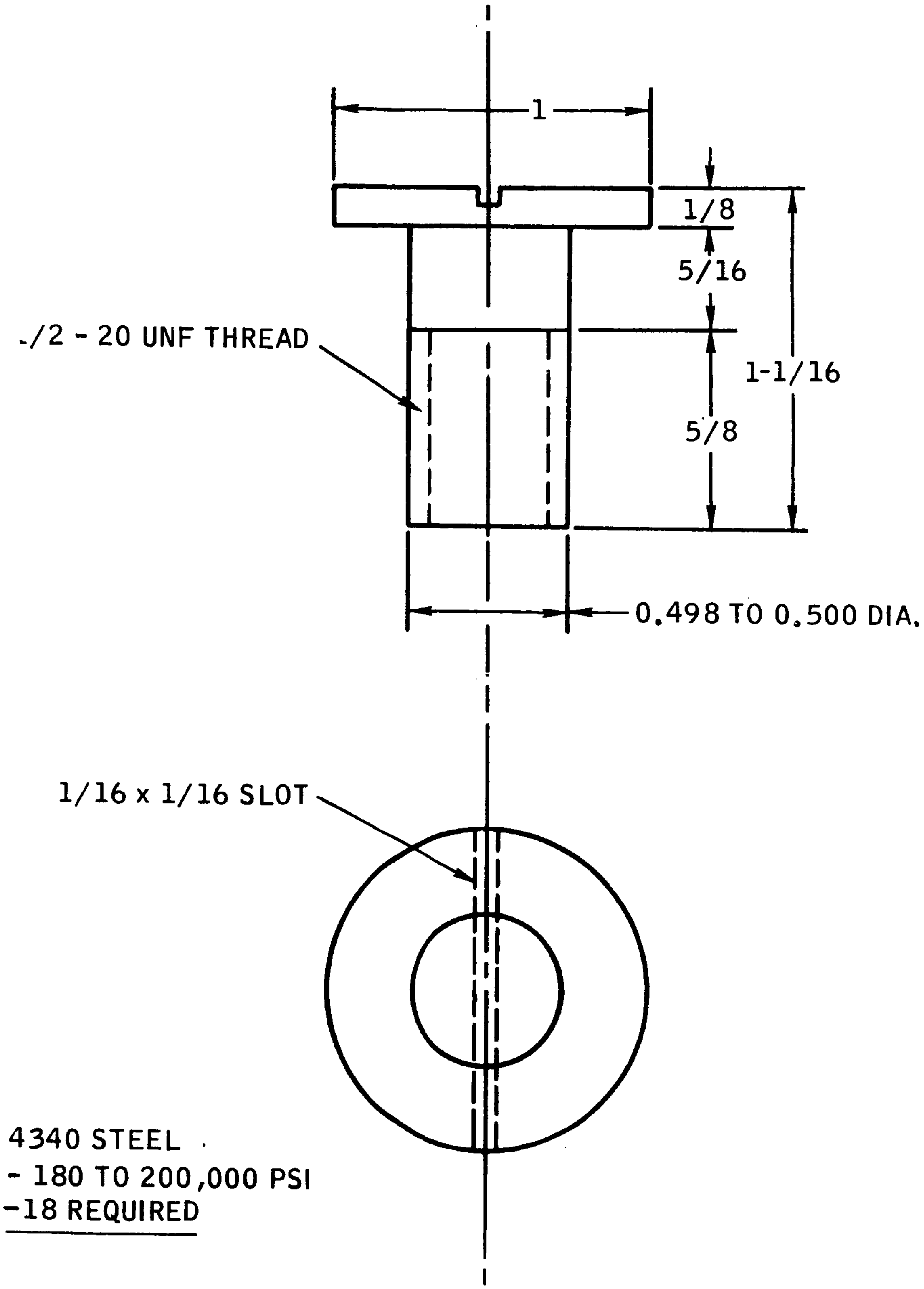
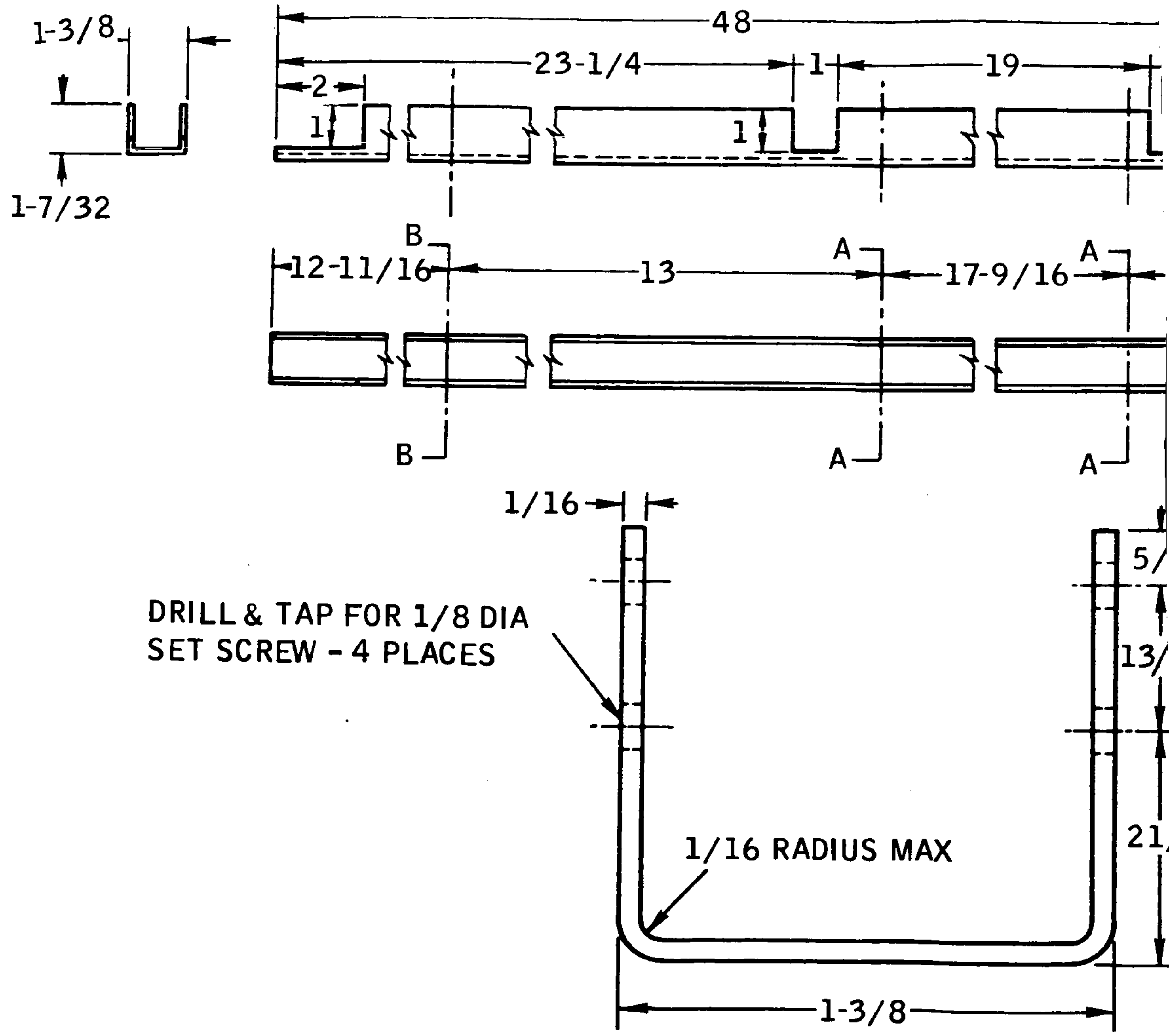


Figure 103. Specimen Attach Pin



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SECTION A-A

2

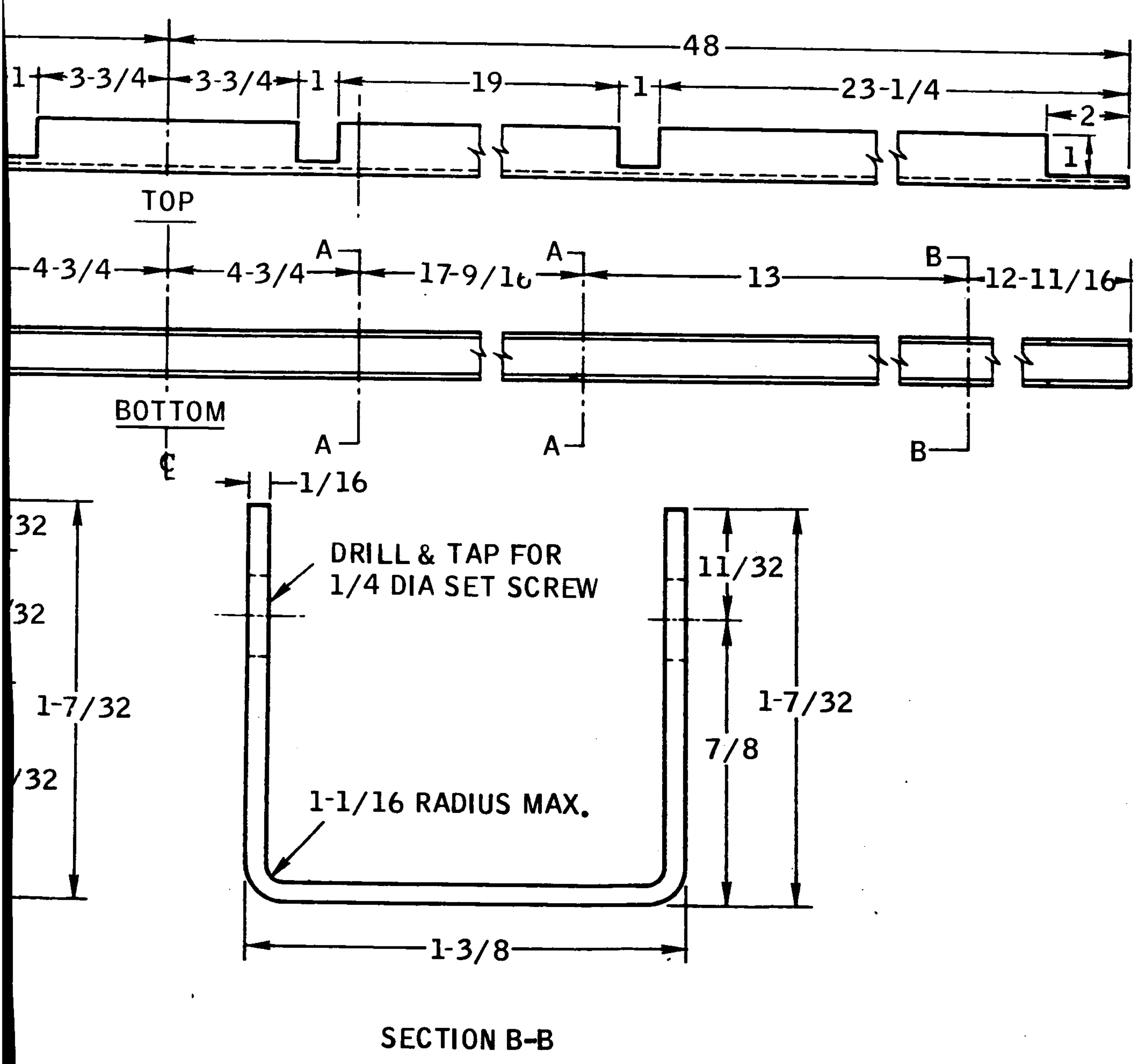


Figure 104. Specimen Assembly Support

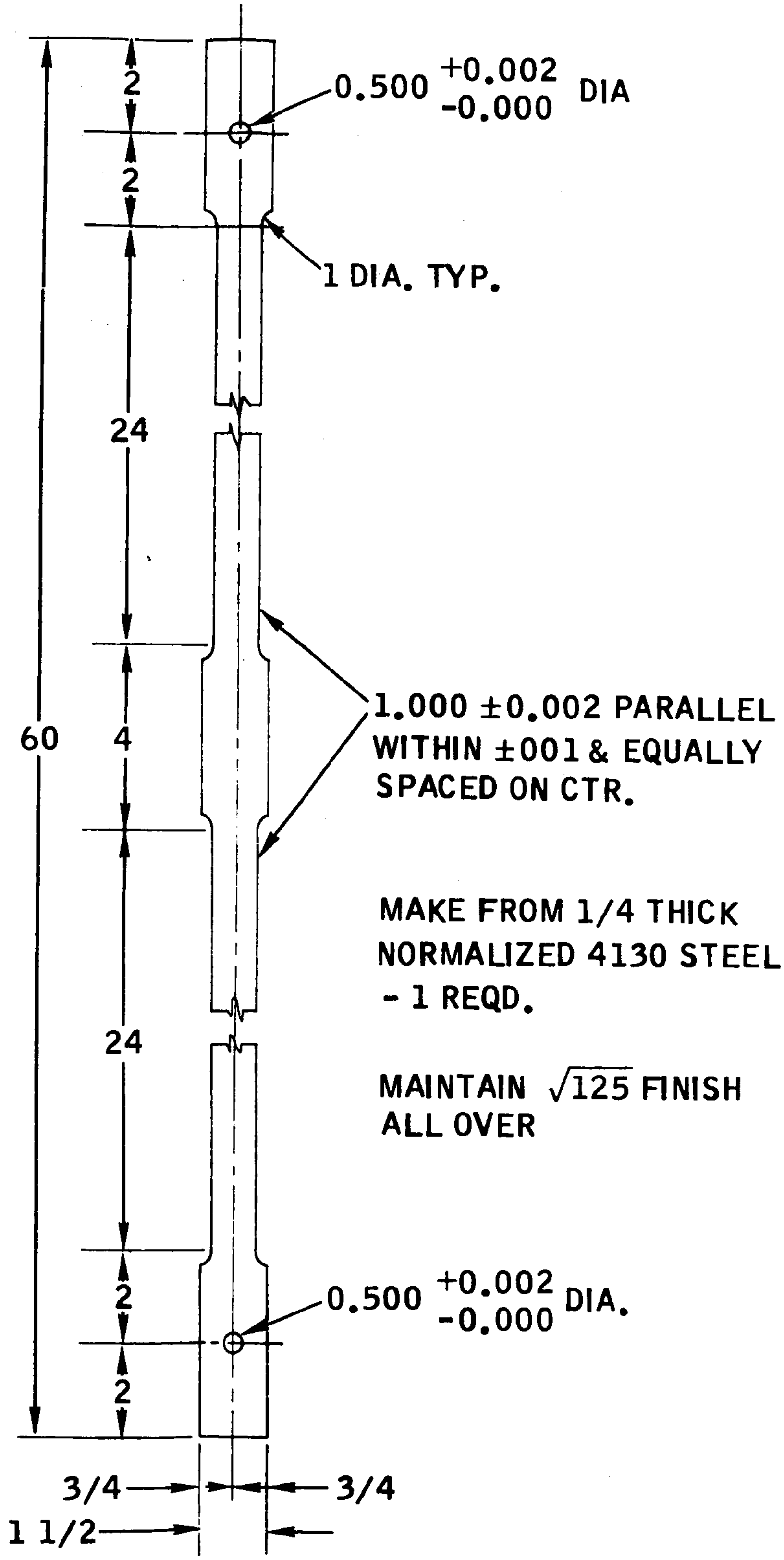


Figure 105. Dynamometer Body

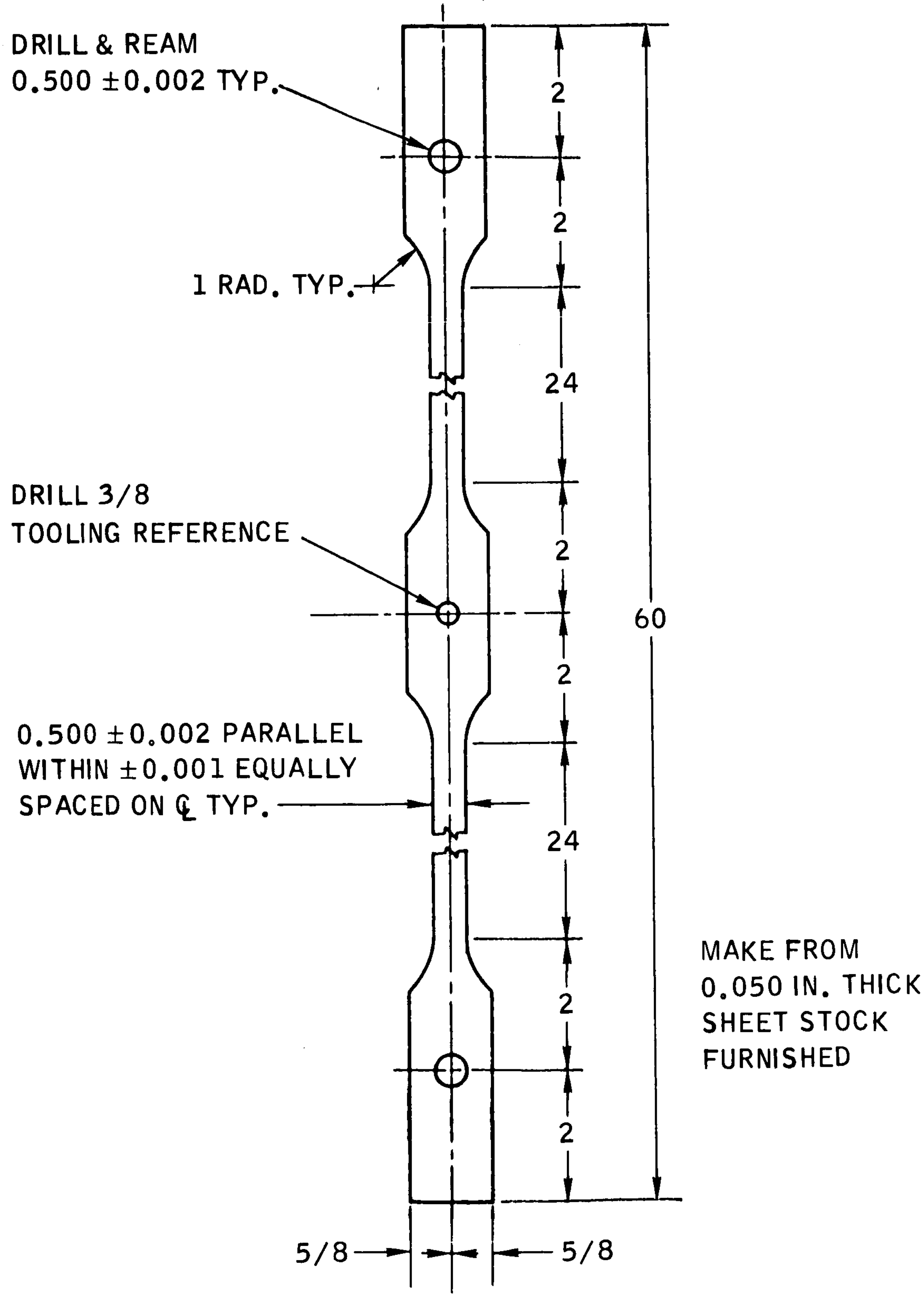


Figure 106. Creep Test Specimen

C3248(115)

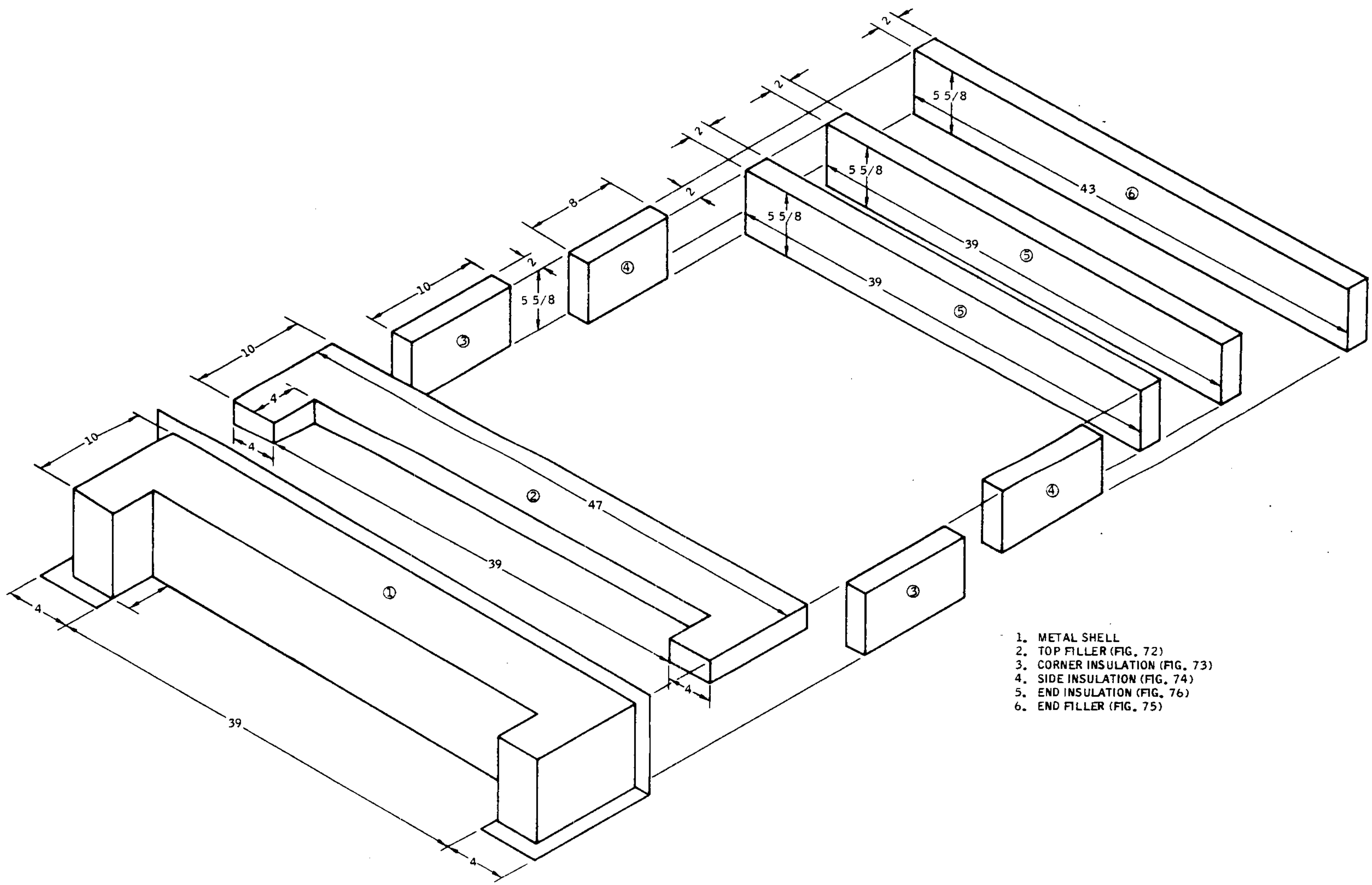


Figure 107. Revised Access Cover

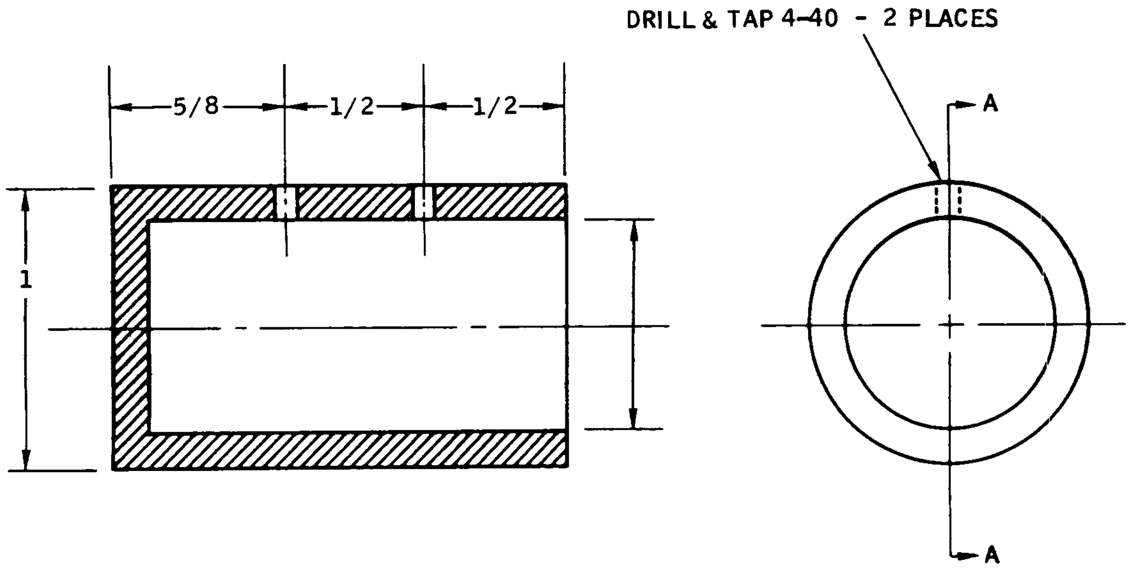


Figure 108. Transducer Retainer

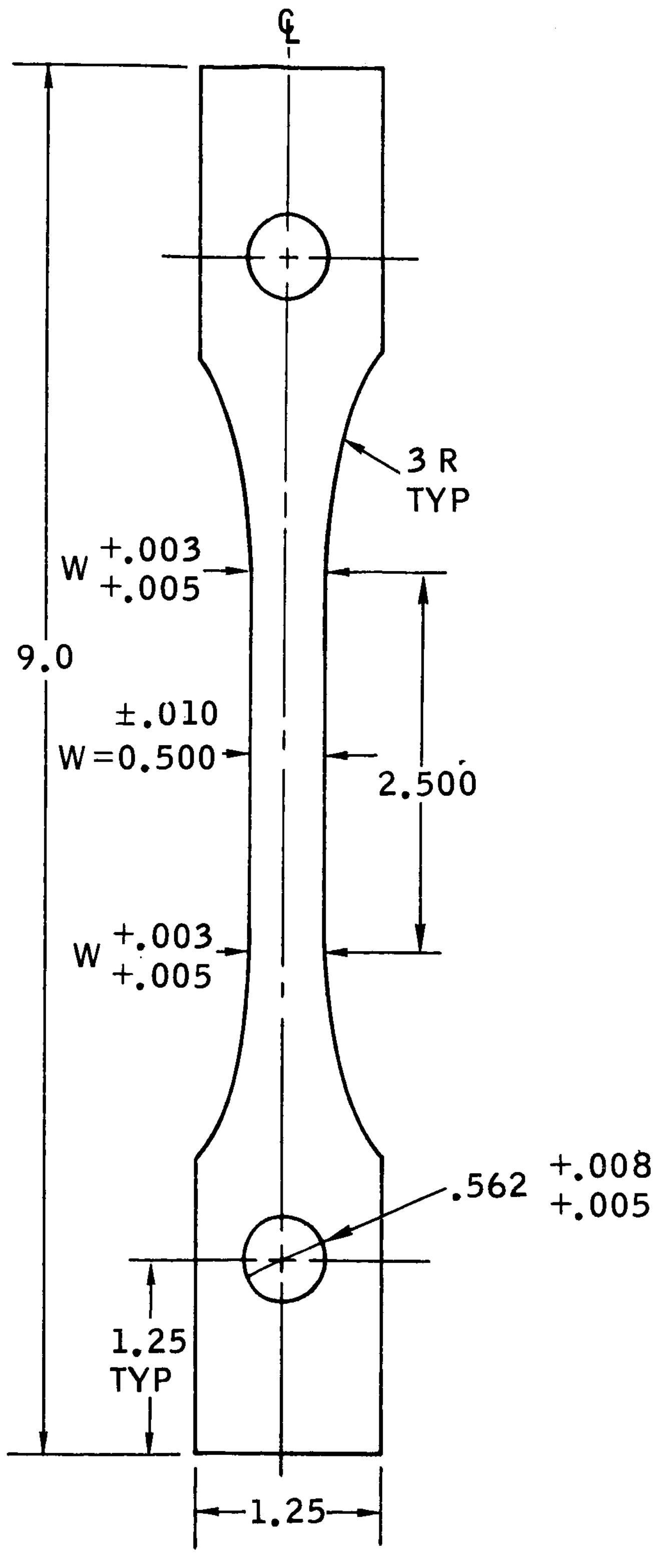


Figure 109. Tension Test Specimen

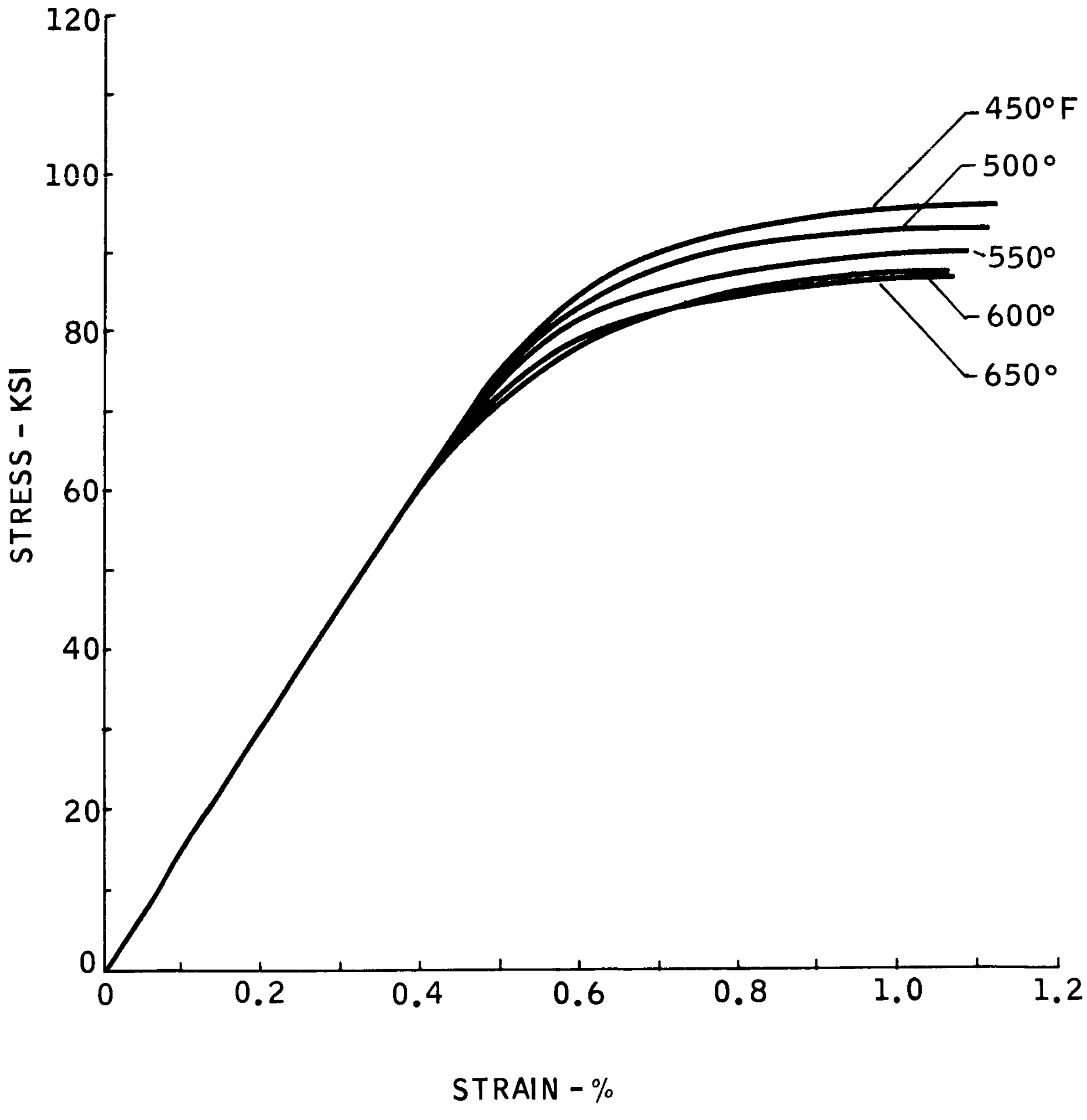


Figure 110. Elevated Temperature Stress
Strain Diagrams for 0.050" Thick Ti-8Al-1Mo-1V Duplex Annealed Sheet.
Titanium Metals Corporation of American Heat V-1555

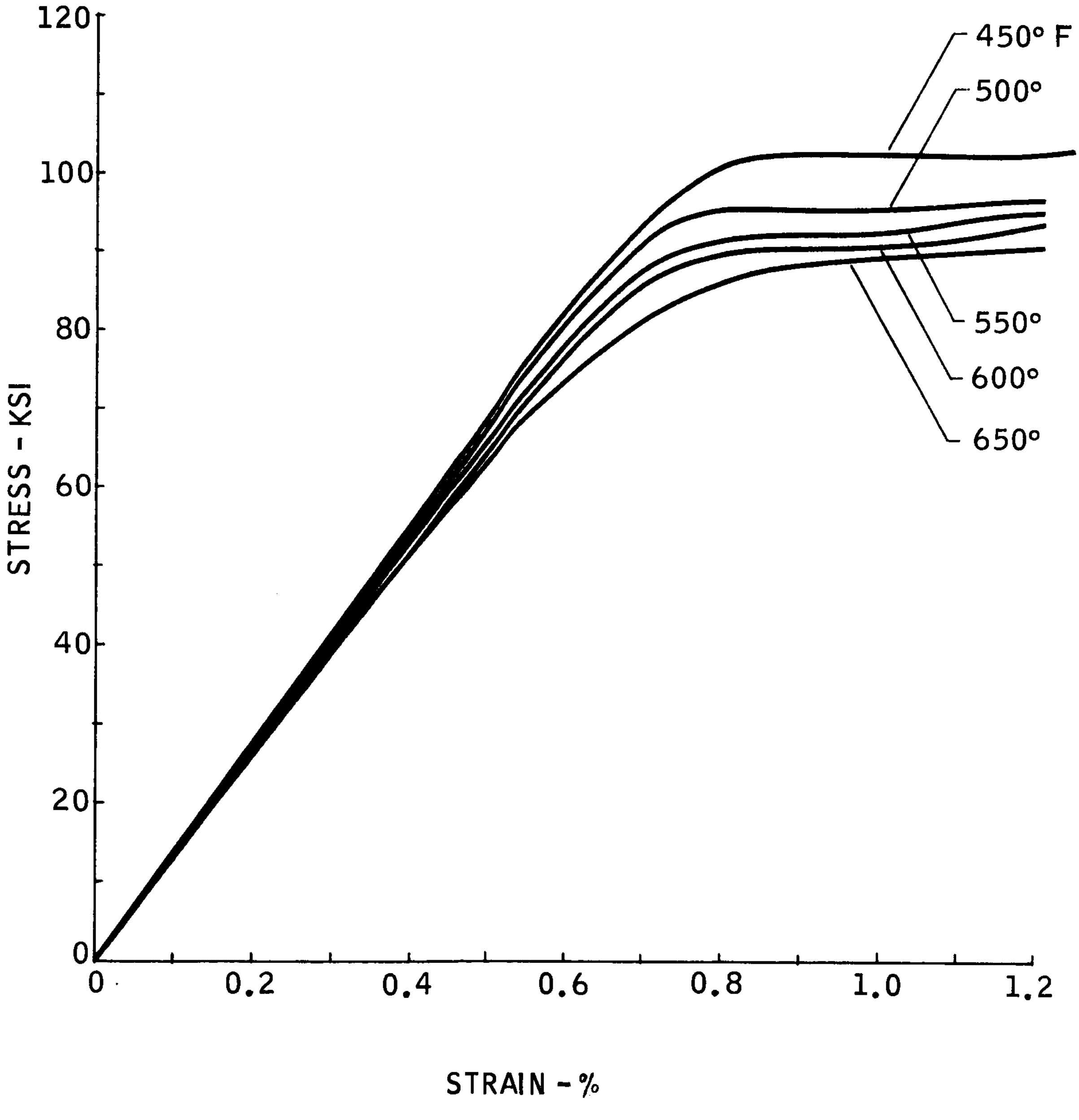


Figure 111. Elevated Temperature Stress Strain Diagrams For 0.050" Thick Ti-6Al-4V Annealed Sheet, Titanium Metals Corporation of American Heat D-4231

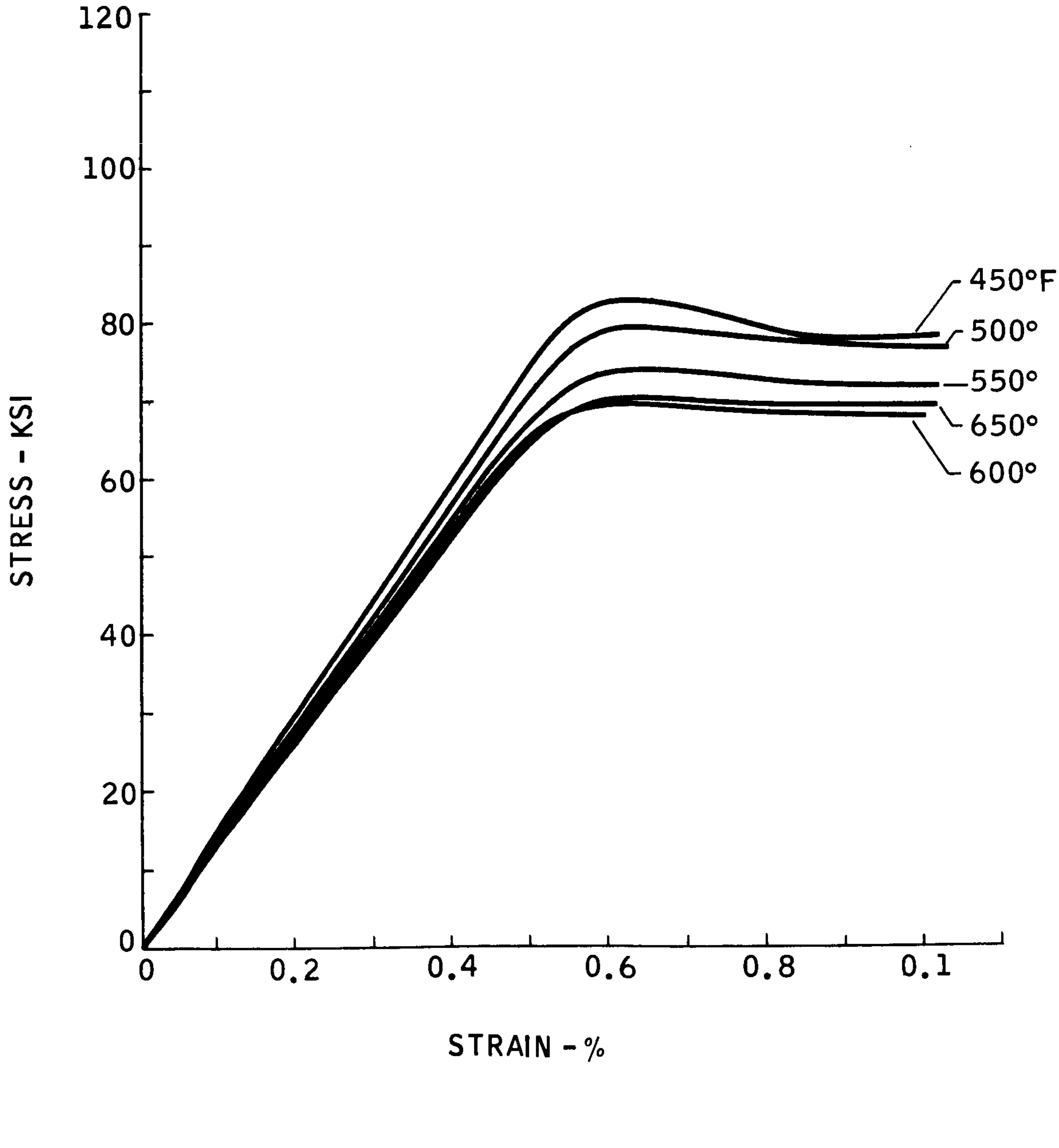


Figure 112. Elevated Temperature Stress
- Strain Diagrams for 0.050" Thick Ti-5Al-2 1/2Sn Annealed Sheet.
Titanium Metals Corporation of American Heat D-2242

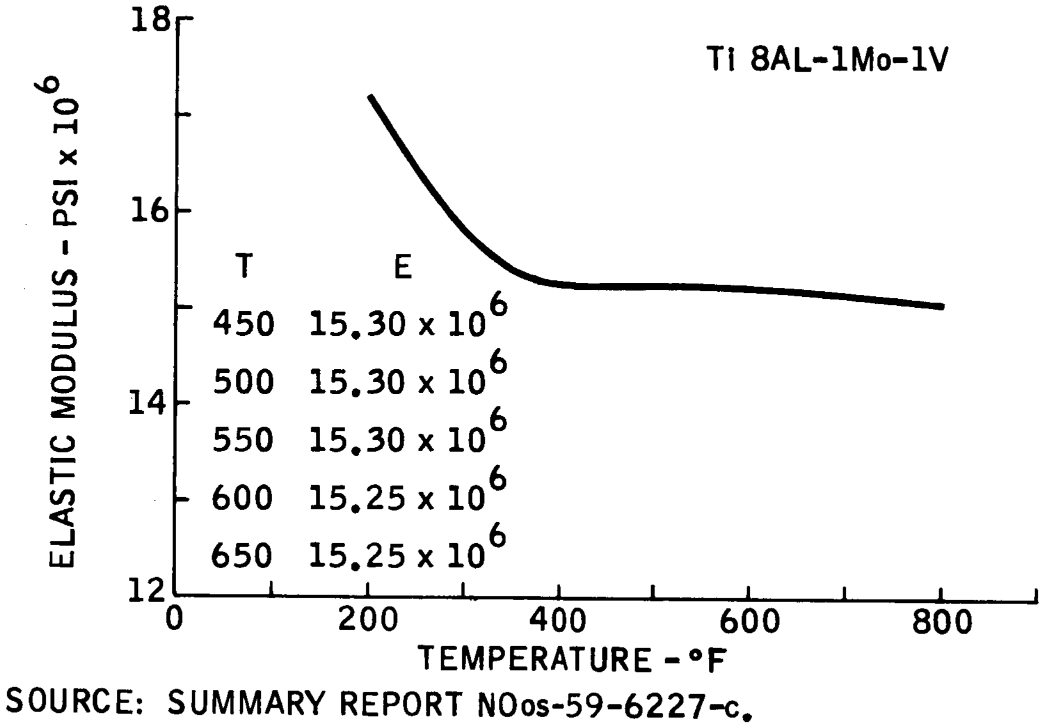


Figure 113. Ti-8Al-1Mo-1V Elastic Modulii

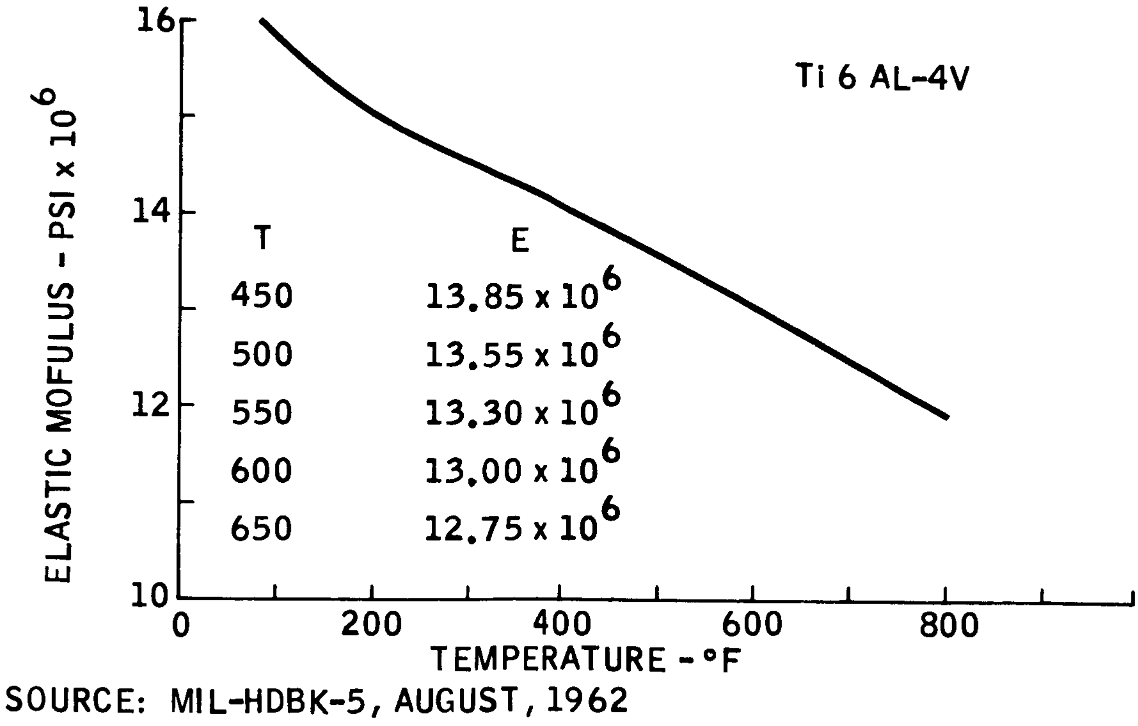
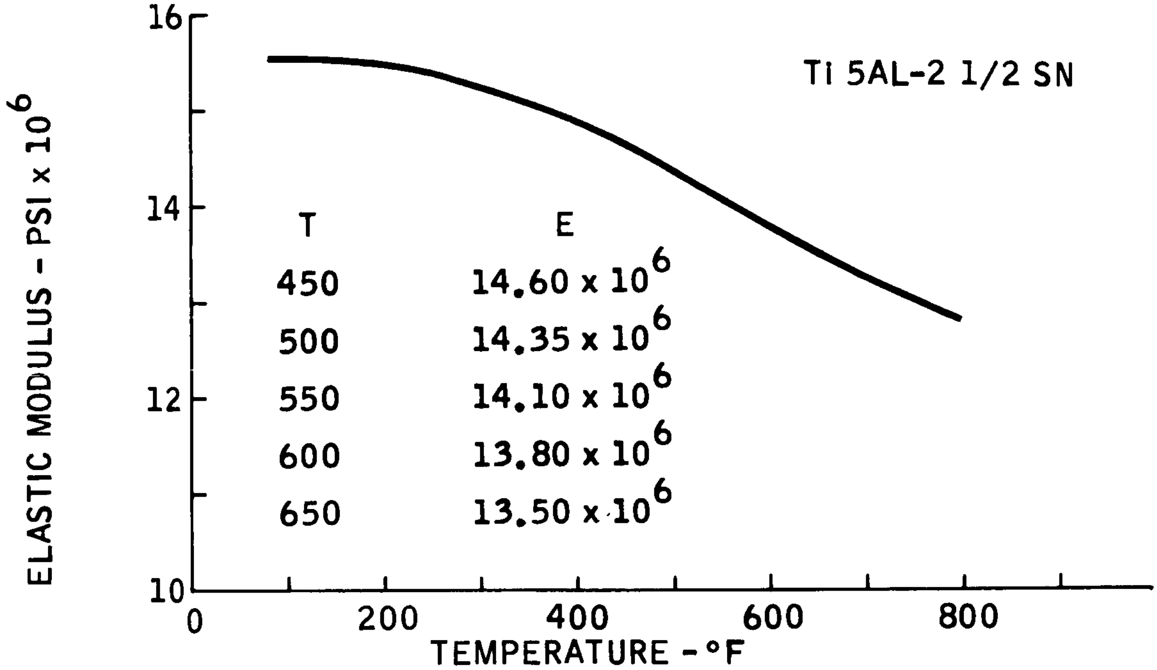


Figure 114. Ti-6Al-4V Elastic Modulii



SOURCE: MIL-HDBK-5, AUGUST, 1962

Figure 115. Ti-5Al-2 1/2 Sn Elastic Modulii

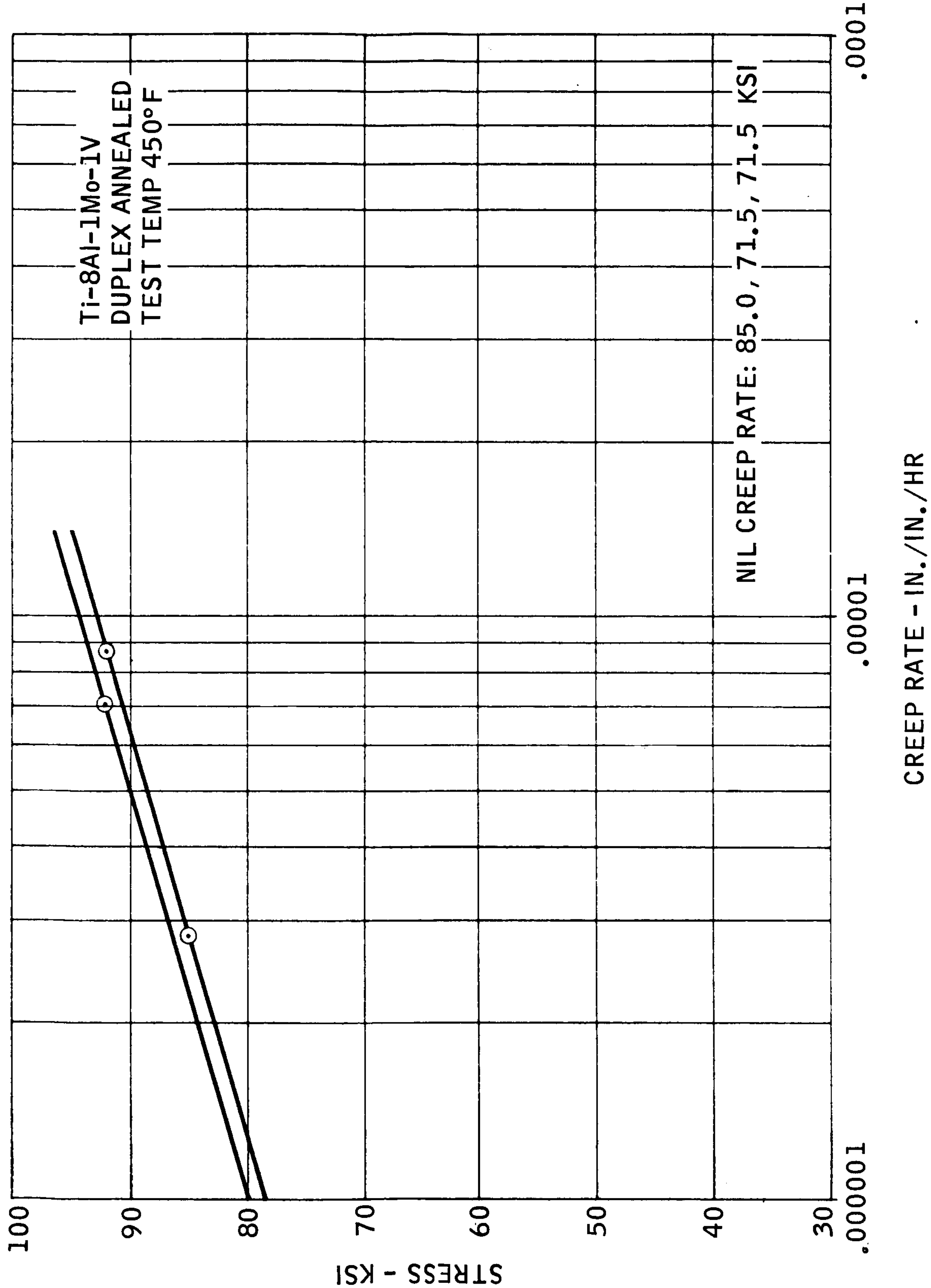


Figure 116. Stress Versus Creep Rate, Ti-8Al-1Mo-1V, 450° F

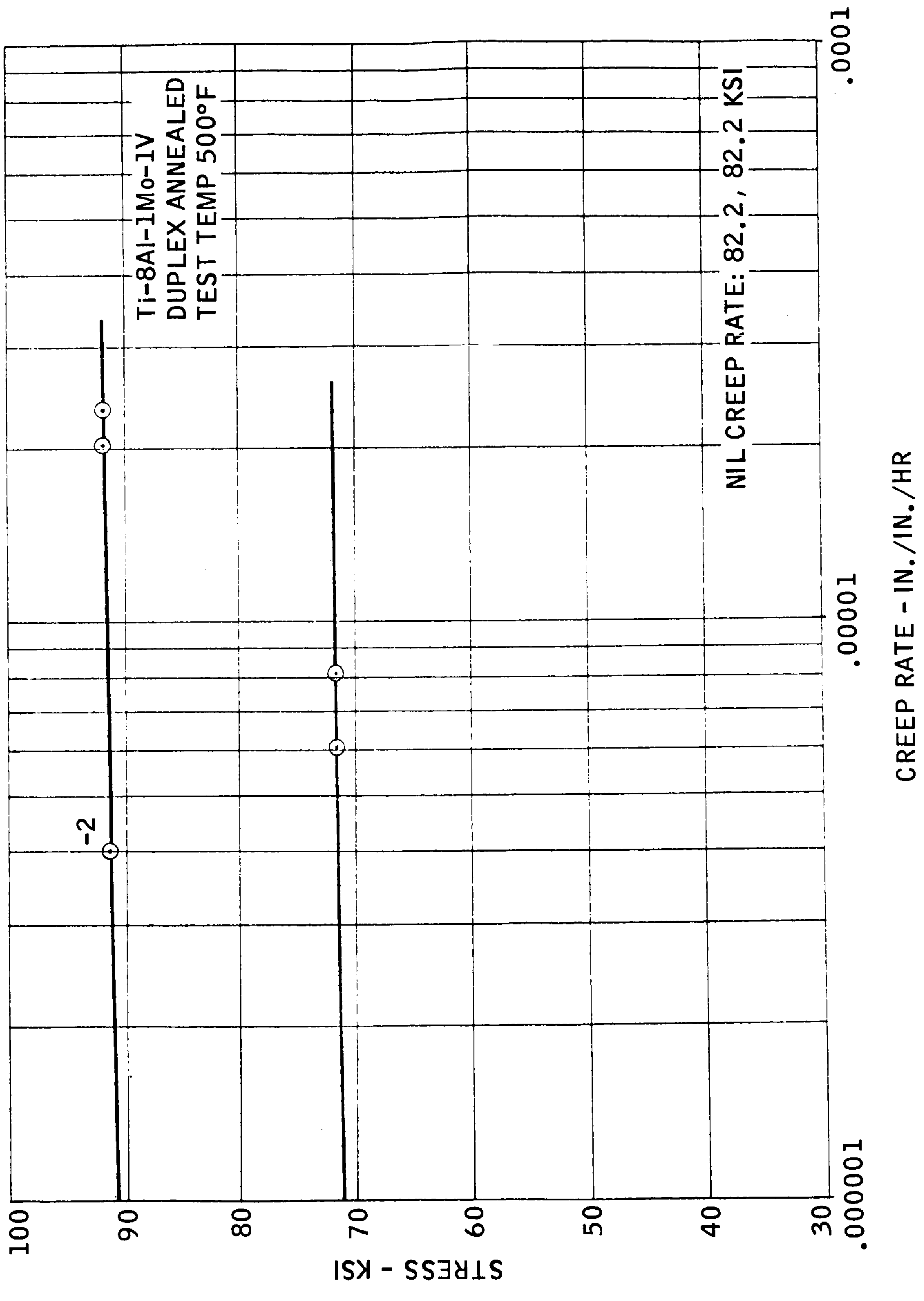


Figure 117. Stress Versus Creep Rate, Ti-8Al-1Mo-1V, 500° F.

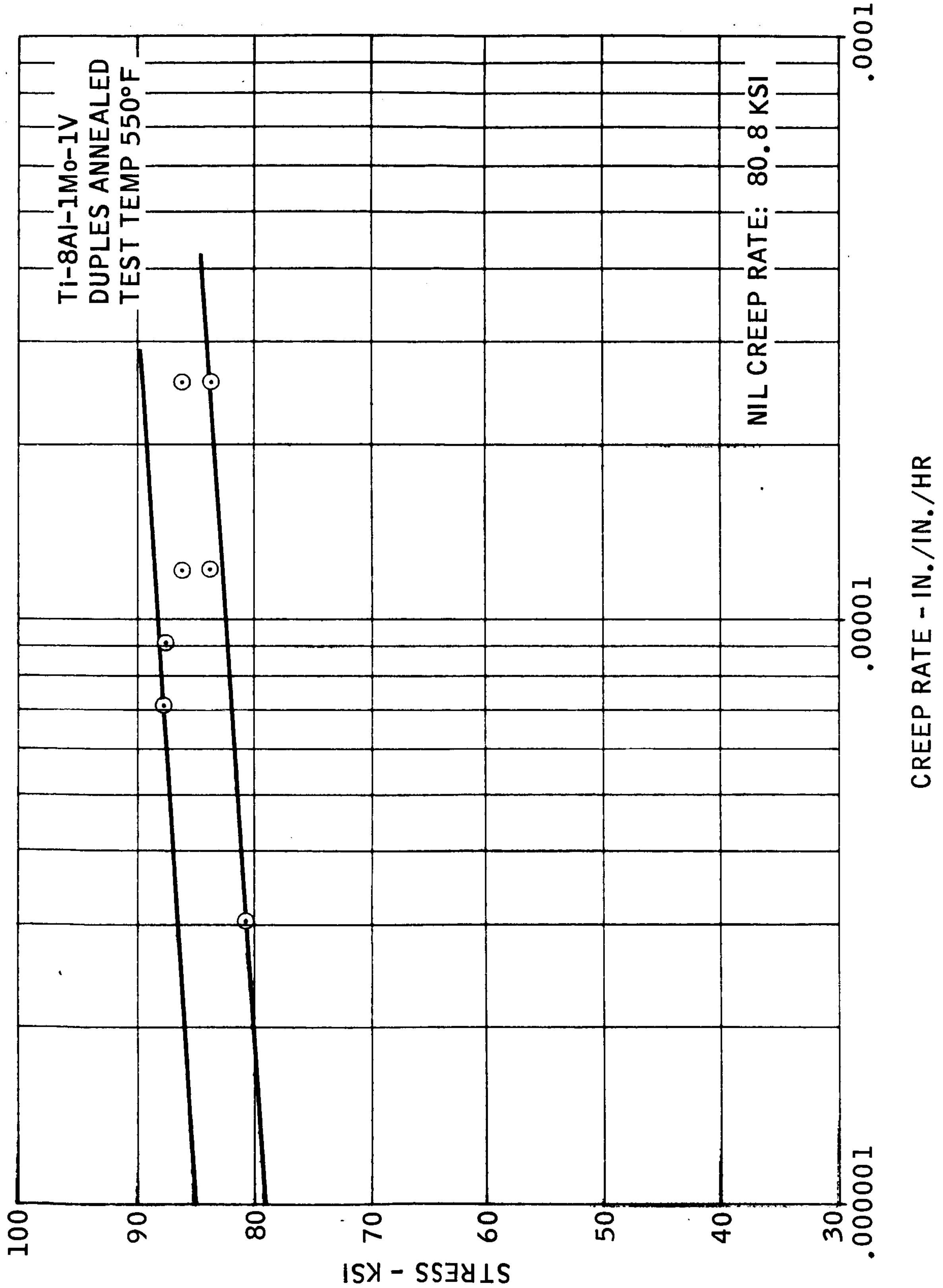


Figure 118. Stress Versus Creep Rate, Ti-8Al-1Mo-1V, 550° F

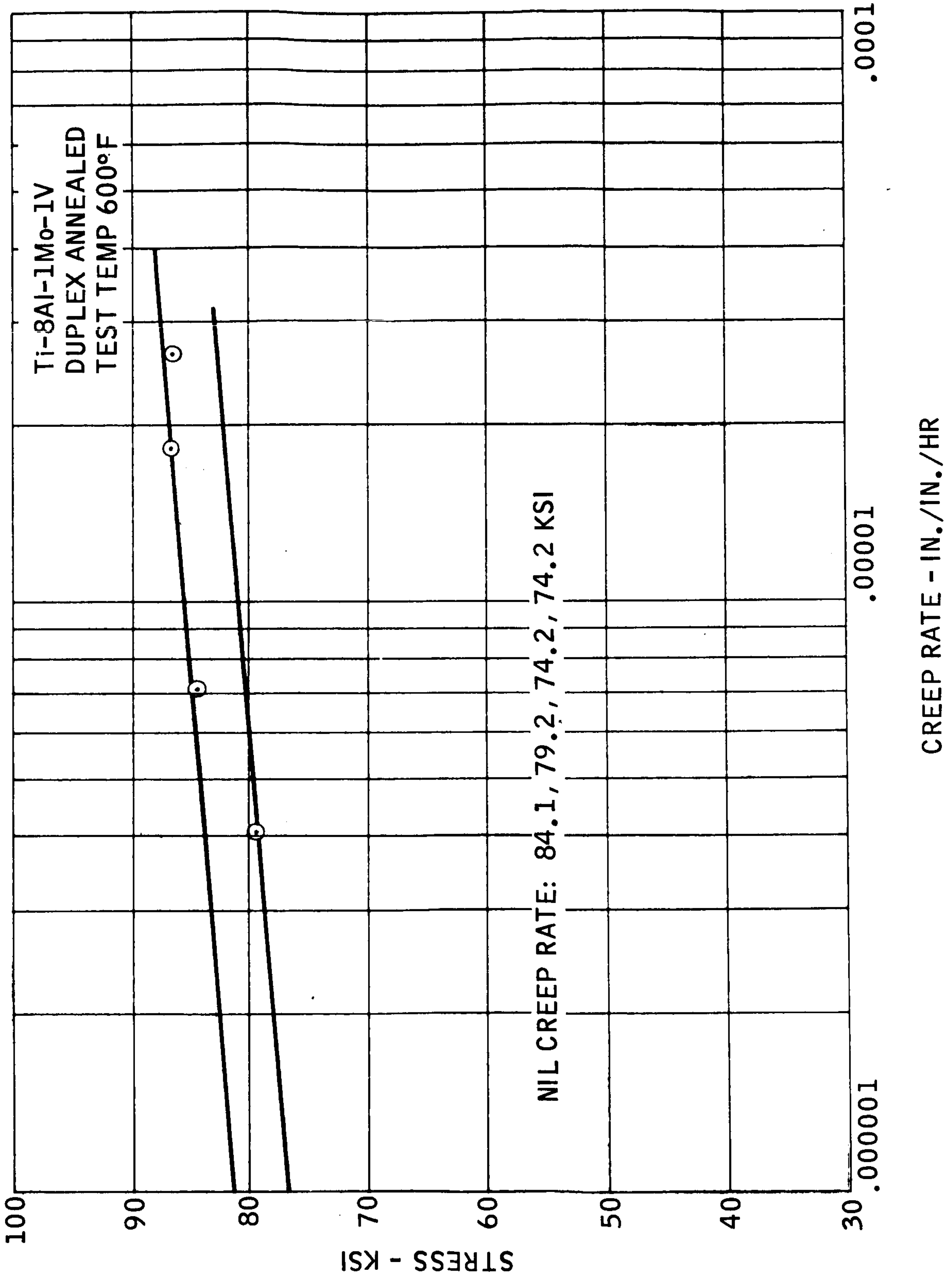


Figure 119. Stress Versus Creep Rate, Ti-8Al-1Mo-1V, 600° F

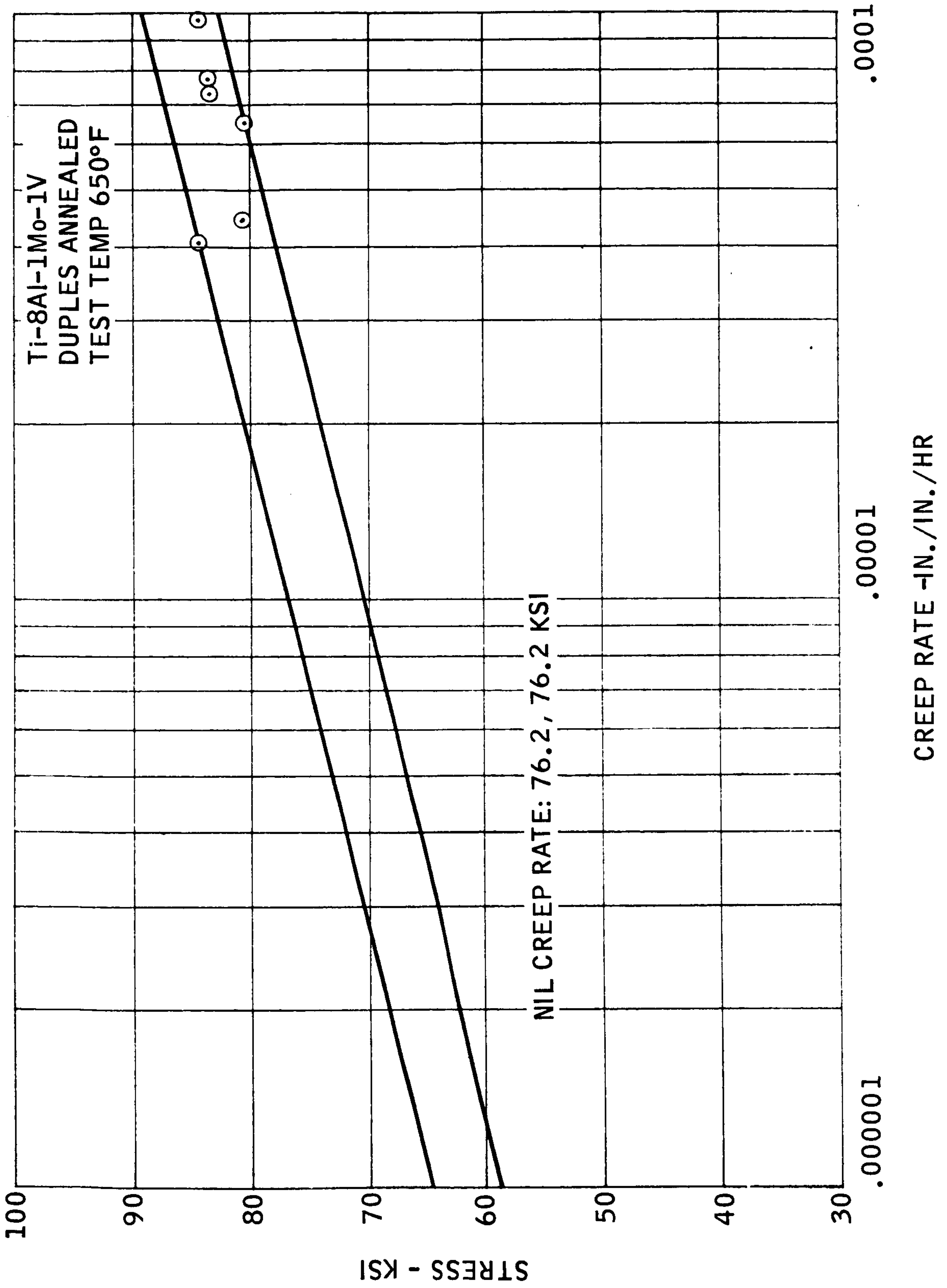


Figure 120. Stress Versus Creep Rate, Ti-8Al-1Mo-1V, 650°F

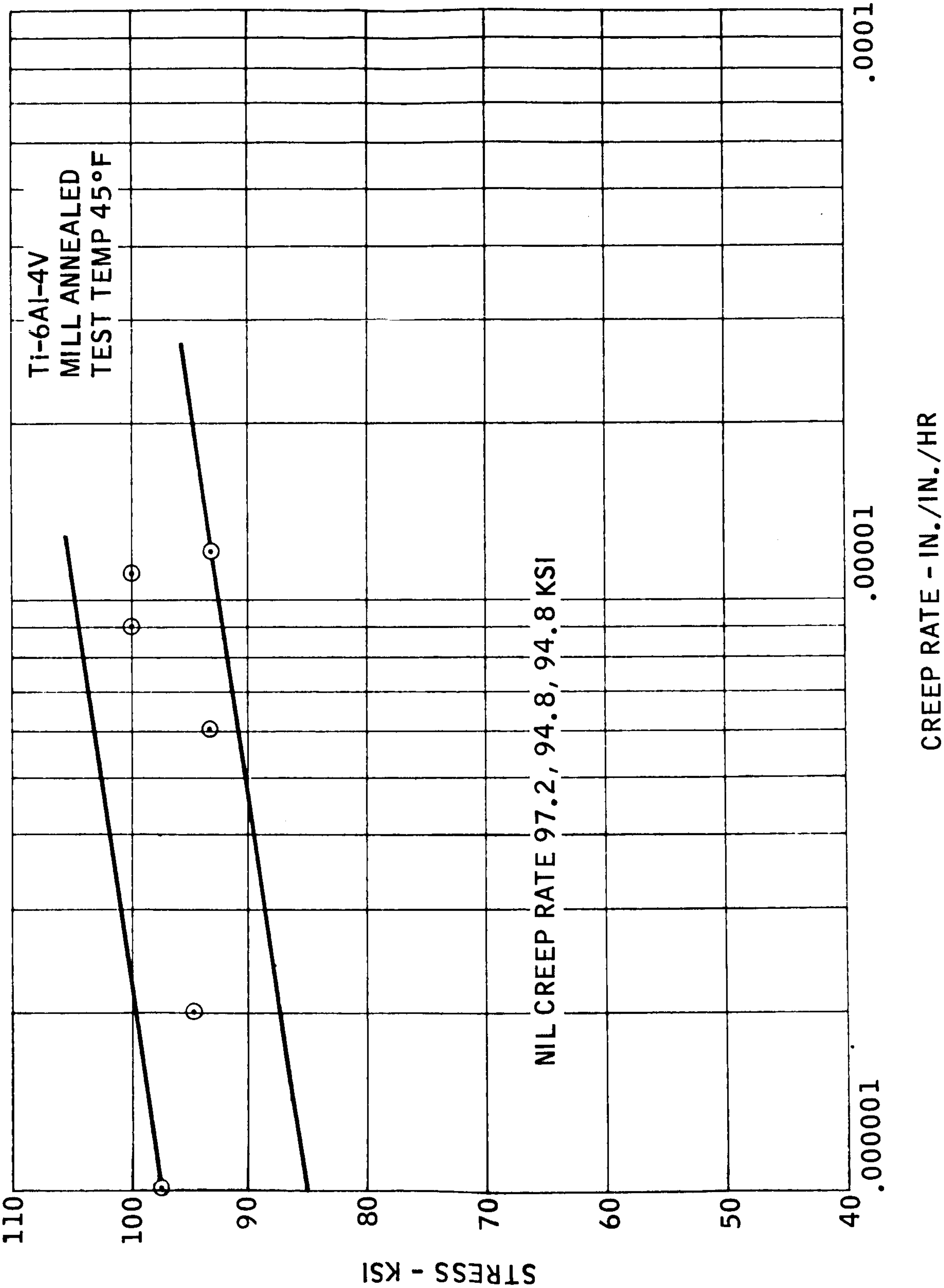


Figure 121. Stress Versus Creep Rate, Ti-6Al-4V, 450° F

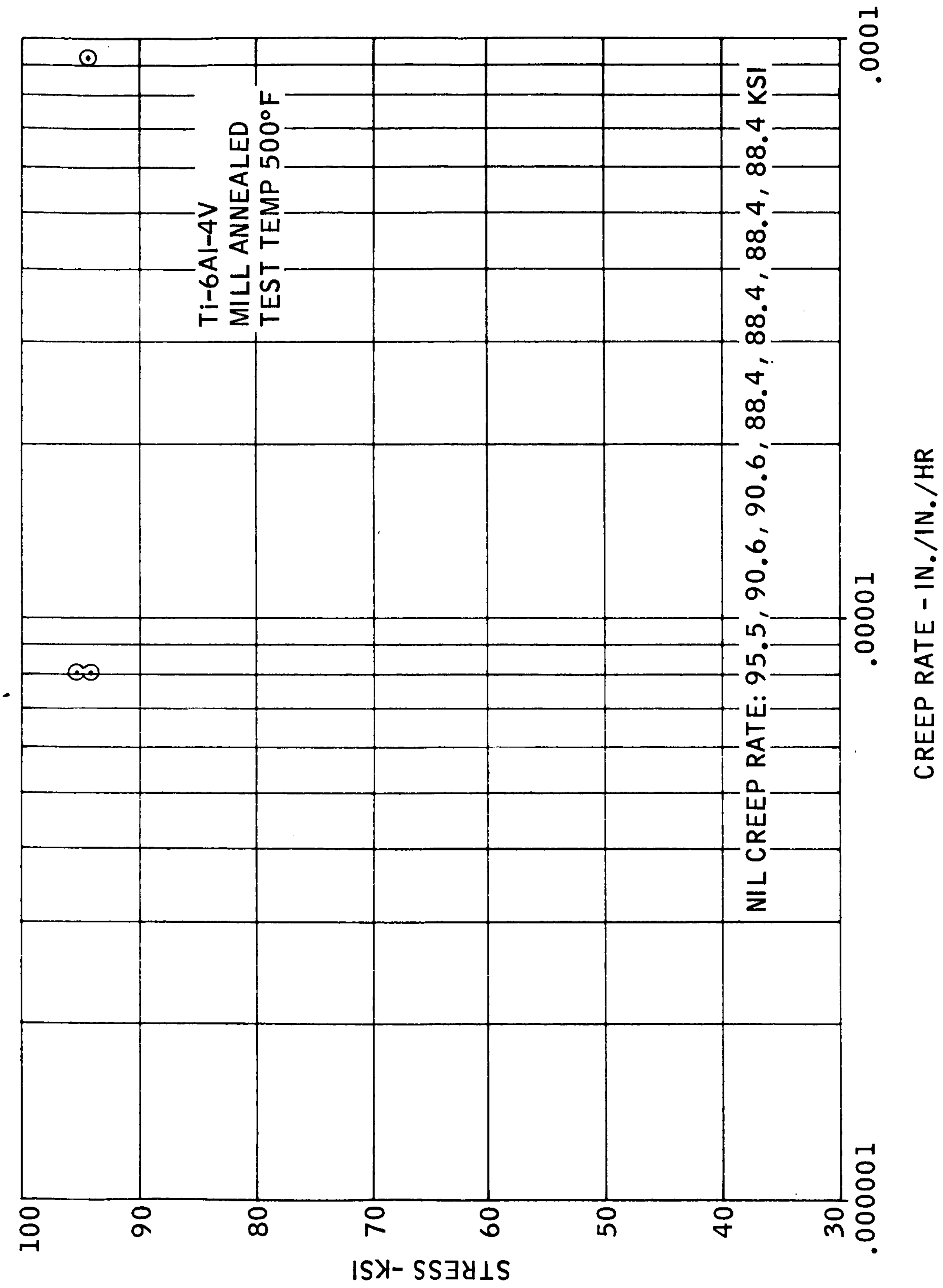


Figure 122. Stress Versus Creep Rate, Ti-6Al-4V, 500° F

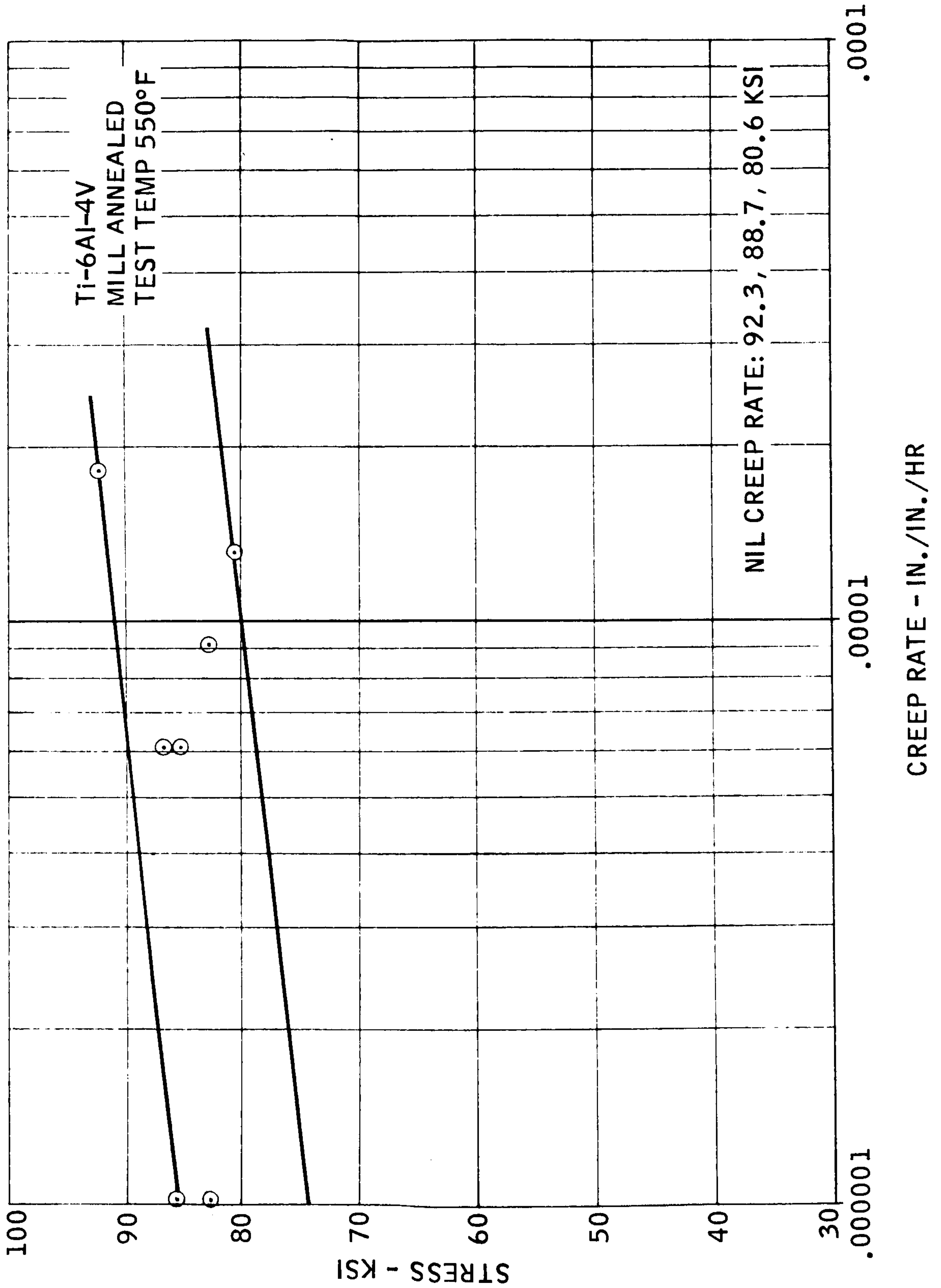


Figure 123. Stress Versus Creep Rate, Ti-6Al-4V, 550° F

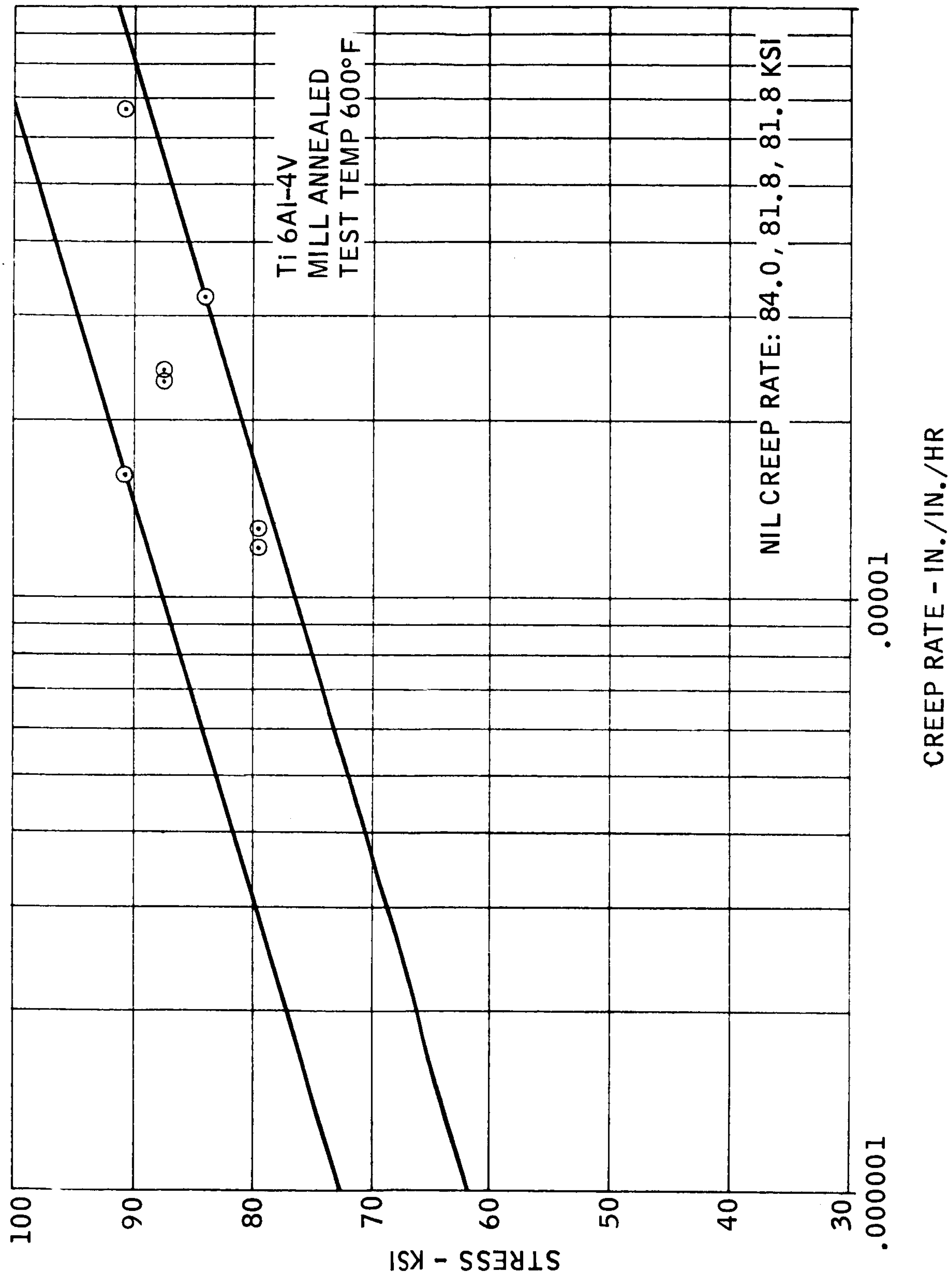


Figure 124. Stress Versus Creep Rate, Ti-6Al-4V, 600 °F

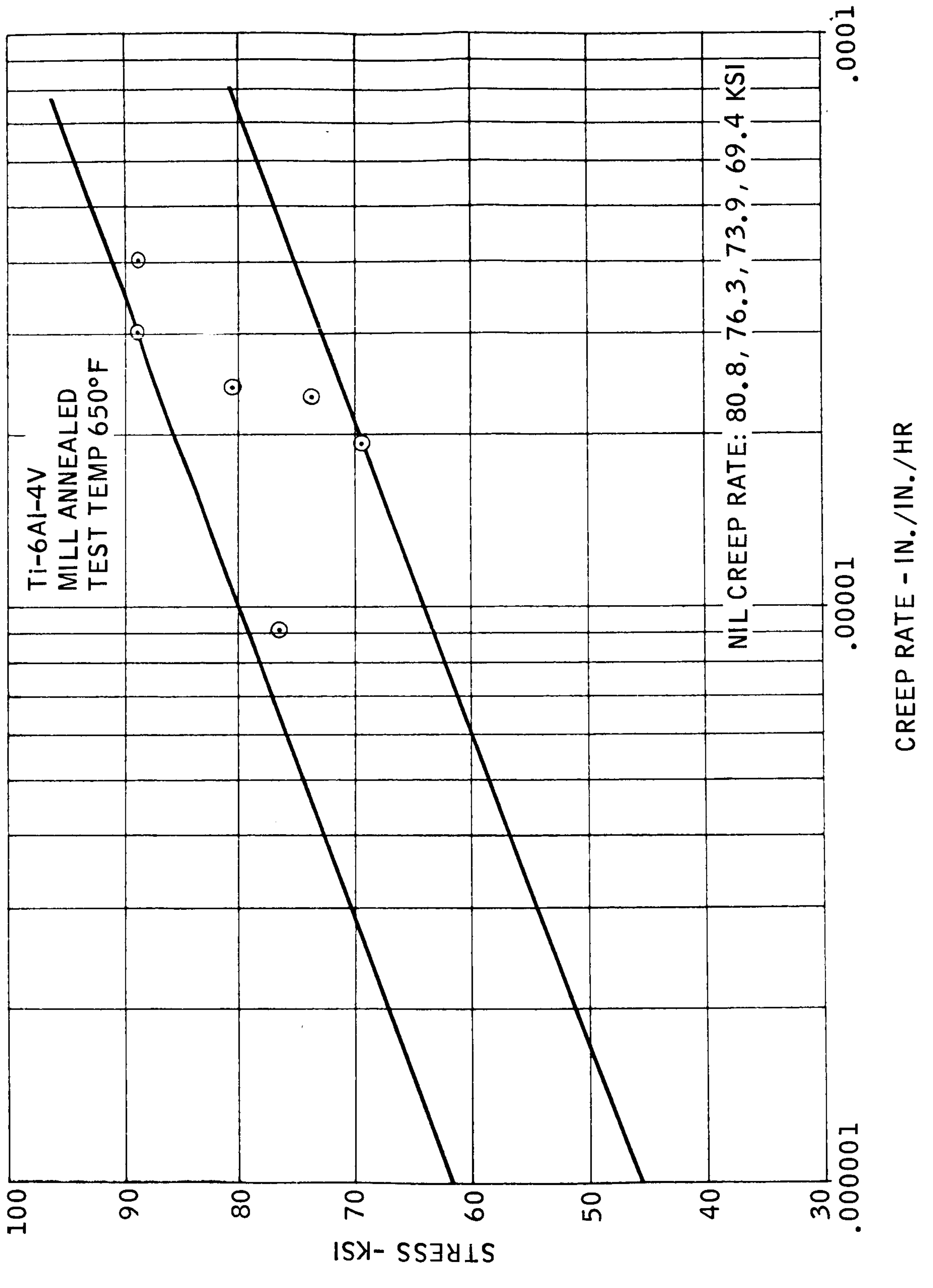


Figure 125. Stress Versus Creep Rate, Ti-6Al-4V, 650°F

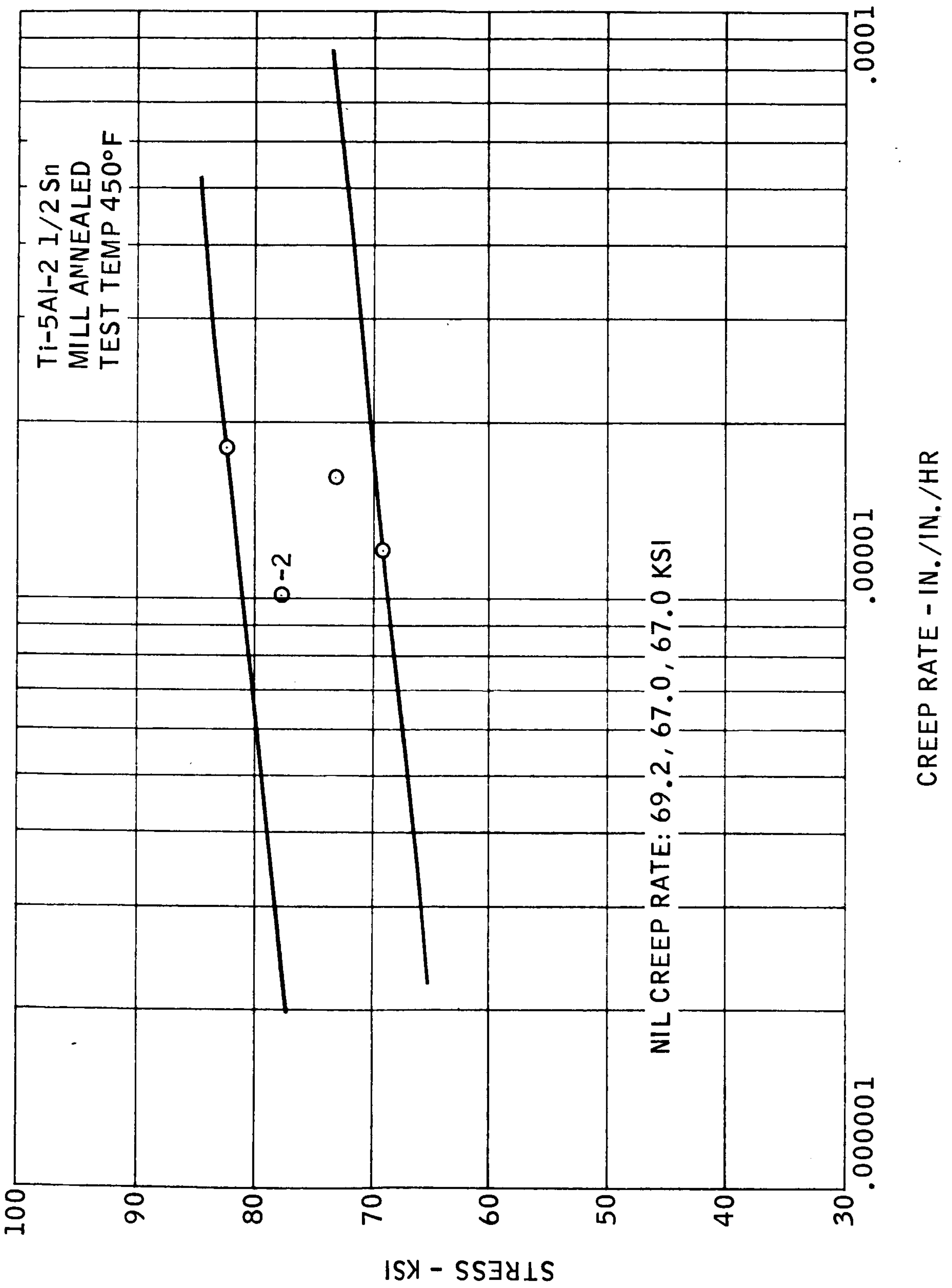


Figure 126. Stress Versus Creep Rate, Ti-5Al-2 1/2 Sn, 450°F

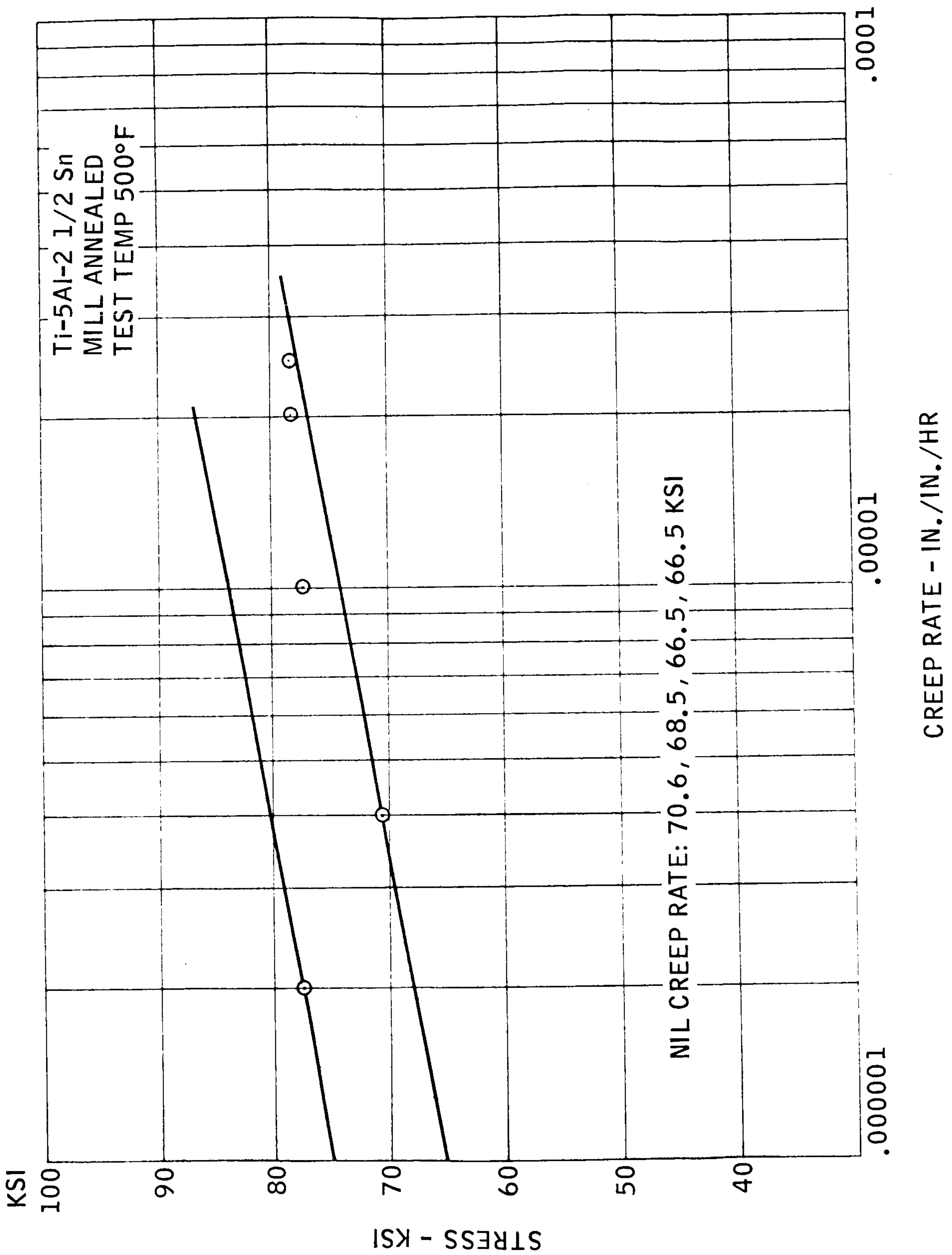


Figure 127. Stress Versus Creep Rate, Ti-5Al-2 1/2 Sn, 500° F

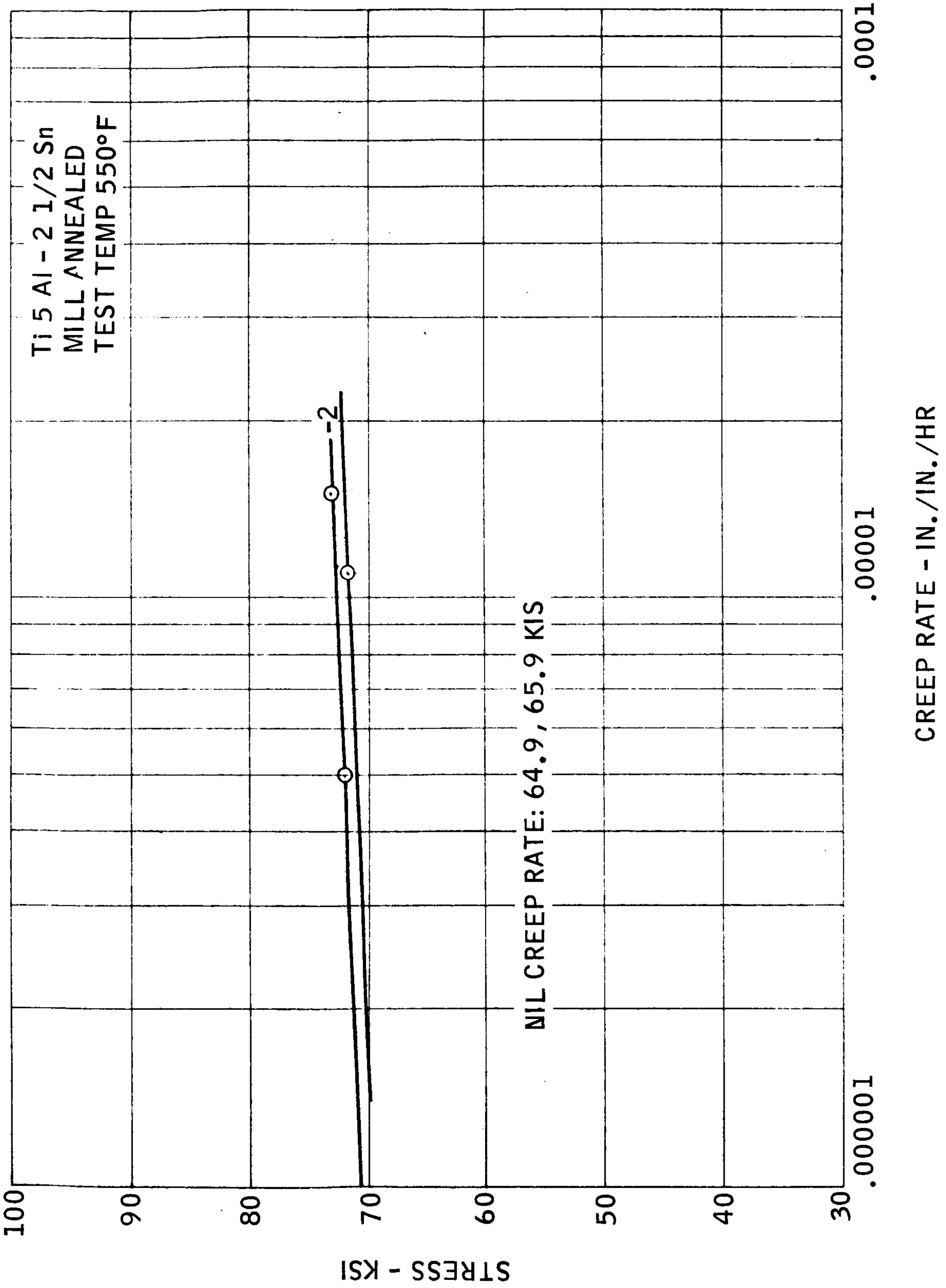


Figure 128. Stress Versus Creep Rate, Ti-5Al-2 1/2 Sn, 550° F

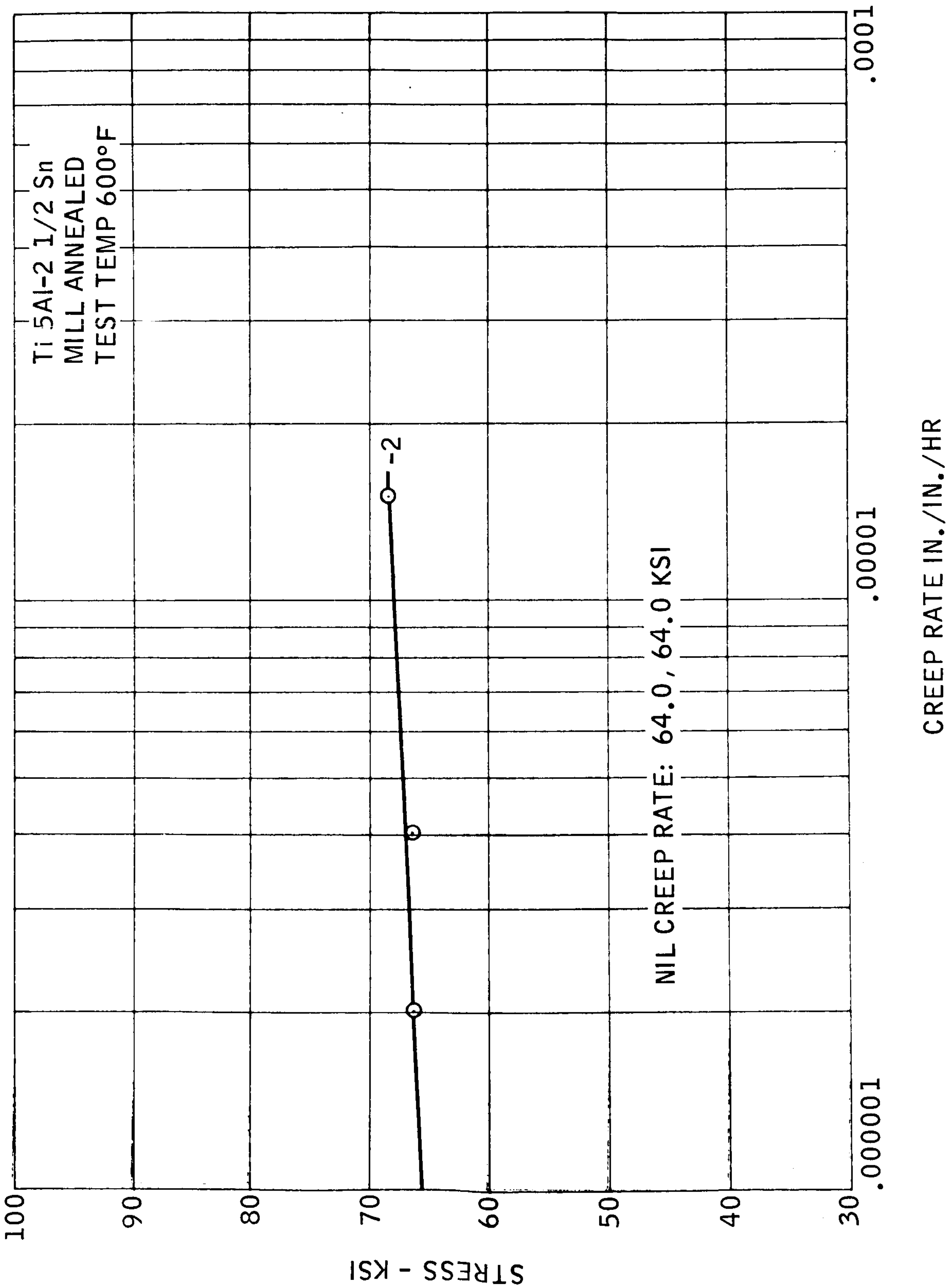


Figure 129. Stress Versus Creep Rate, Ti-5Al-2 1/2 Sn, 600°F

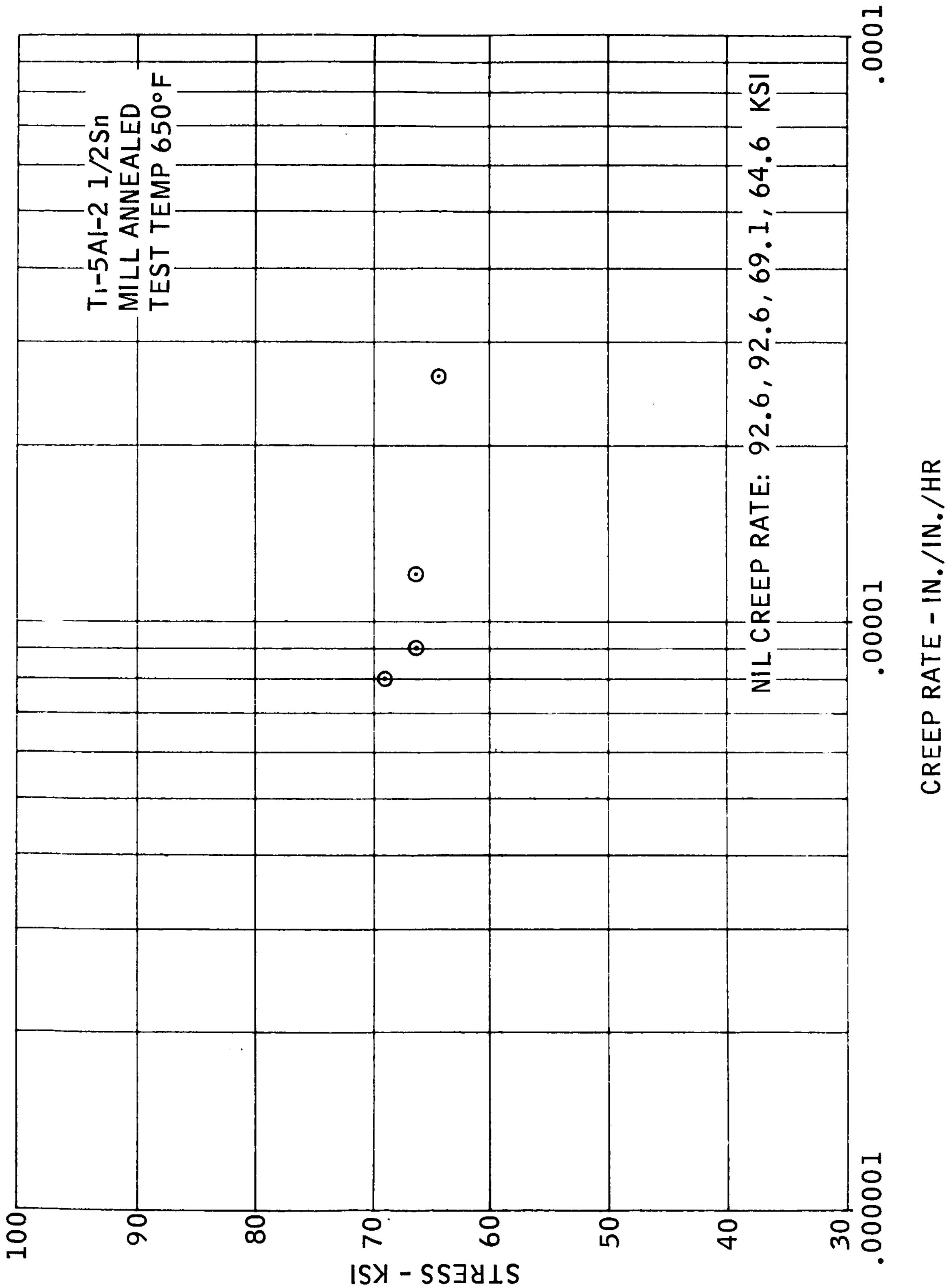


Figure 130. Stress Versus Creep Rate, Ti-5Al-2 1/2 Sn, 650° F

APPENDIX A

INSTALLATION AND OPERATION INSTRUCTIONS
KAVLICO ELECTRONICS, INC.
GM-2105, SERIAL NO. 1001

1. SET-UP

   1.1 Connect the Transducers to Junction Blocks J1 thru J9 at the rear of the CONTROL PANEL chassis.

   1.2 Plug the AC POWER CORD (Accessible from the back side of the console) into an 115 volt 60 cycle outlet.

2. POWER

   2.1 Turn the Power Supply LINE switch to ON position.

   2.2 Set the DC Null Meter RANGE switch to 10 (VOLTS).

   2.3 Turn the DC Null Voltmeter POWER switch to ON position.

   2.4 Turn the Power Supply OUTPUT switch to ON position.

   Note: A safety time delay relay is incorporated in the output line to give a minimum of 30 seconds delay after turning on the power supply line switch.

3. TRANSDUCER MECHANICAL NULL

   3.1 Set CONTROL PANEL SWITCHES as follows:

      A. Set the CHANNEL SELECTOR switch to the transducer to be adjusted (MT-1 thru MT-9).

      B. Set the MECH NULL switch to MECH NULL.

      C. Set the POLARITY switch to direction of displacement to be measured (IN or OUT).

D. Set the RANGE switch to desired full scale displacement (.03 IN or .003 IN).

E. DISPLACEMENT potentiometer under the MT number under test to 000.

3.2 Reset the DC NULL VOLTMETER RANGE (VOLTS) switch as required to indicate the off null condition.

3.3 Position the transducer core for minimum NULL METER deflection, while resetting the DC NULL VOLTMETER as in paragraph 3.2 above.

3.4 Repeat paragraph 3.1 thru 3.3 for each transducer (MT-1 thru MT-9) used.

4. ZERO SET

4.1 Set CONTROL PANEL SWITCHES as follows:

A. Set the CHANNEL SELECTOR switch to the transducer to be adjusted (MT-1 thru MT-9).

B. Set the MECH NULL switch to OPERATE.

C. Set the POLARITY switch to direction of displacement to be measured (IN or OUT).

D. Set the RANGE switch to desired full scale displacement (.03 IN or .003 IN).

E. Set the DISPLACEMENT potentiometer under the MT (transducer) number under test to 000.

4.2 Reset the DC NULL VOLTMETER RANGE (VOLTS) switch as required to indicate the off null condition.

4.3 Set the COARSE ZERO adjustment switch (located under the MT number under test) for minimum NULL METER deflection, while resetting the DC NULL VOLTMETER as in paragraph 4.2 above.

4.4 Adjust the FINE ZERO adjustment potentiometer (located under the COARSE ZERO adjustment switch used in paragraph 4.3 above) for minimum NULL METER deflection, while resetting the DC NULL VOLTMETER as in paragraph 4.2 above. When the null adjustment is completed, lock the potentiometer to avoid accidental movement. If the potentiometer dial indication is recorded it can be reset if it should be accidentally moved.

4.5 Repeat paragraphs 4.1 thru 4.4 for each transducer (MT-1 thru MT-9) used.

5. DISPLACEMENT MEASUREMENT

5.1 Set CONTROL PANEL SWITCHES as follows:

A. CHANNEL SELECTOR switch to the transducer to be measured (MT-1 thru MT-9).

B. MECH NULL switch to OPERATE.

C. POLARITY switch to direction of displacement to be measured (IN or OUT).

D. RANGE switch to desired full scale displacement (.03 IN or .003 IN).

5.2 Reset the DC NULL VOLTMETER RANGE (VOLTS) switch as required to indicate the off null condition.

5.3 Adjust the DISPLACEMENT potentiometer, corresponding to the transducer selected in paragraph 5.1A above, for minimum NULL METER deflection, while resetting the DC NULL VOLTMETER as in paragraph 5.2 above. A lock is provided to avoid accidental movement after a null has been established and should be used if the DISPLACEMENT potentiometer indication is not recorded.

5.4 Repeat paragraphs 5.1 thru 5.3 for each transducer to be measured.

APPENDIX B

MAINTENANCE INSTRUCTIONS
KAVLICO ELECTRONICS, INC.
GM-2105, SERIAL NO. 1001

1. AC POWER SUPPLY

1.1 OUTPUT VOLTAGE ADJUSTMENT

Access to the power supply for voltage adjustment is attained by removing the eight (8) retaining screws on the front of the CONTROL PANEL and disconnecting the two (2) cables (Red and Black) between the Control Panel OUTPUT and the DC Null Voltmeter INPUT. The Control Panel is mounted on slides and may be pulled forward to expose the top area of the Power Supply. It is desirable that this adjustment be made with full load, e.g., with the transducers connected. Output voltage should be monitored by a precision RMS Voltmeter ($\pm$ 0.2% Max.) while adjusting the FINE adjustment potentiometer, located on the OSC chassis of the power supply, to give an output of 22 volts RMS.

1.2 REPAIR

Detailed prints, schematics, and instructions are contained in the Operational-Maintenance Manual for the power supply and the Instruction Manual for the oscillator. Re-set the output voltage as detailed in paragraph 1.1 after any repair. (References 1 and 2)

2. DC NULL VOLTMETER

2.1 RECORDER OPERATION

Before connecting a recorder to the output jacks note the limitations in paragraph 3-9, section 3 page 1 of the DC Null Voltmeter OPERATING AND SERVICE MANUAL. (Reference 3)

2.2 REPAIR

Detailed maintenance instructions are contained in the DC Null Voltmeter OPERATING AND SERVICE MANUAL. (Reference 3)

3. CONTROL PANEL

3.1 TRANSDUCER REPLACEMENT (Reference 4)

3.1.1 The transducers are serialized and as shipped are calibrated on both ranges (.03 IN and .003 IN) at a temperature of 550°F. Serial Number 1001 is calibrated for MT-1 (Receptacle J1). Serial Numbers 1002 thru 1009 are similarly calibrated such that serial number 1009 is calibrated for MT-9 (Receptacle J9). In making a replacement the change in serial numbers must be noted to avoid errors in operational set-up.

3.1.2 Mount the transducer in a fixture such that the core can be displaced with a micrometer. Accuracy of measurements is dependent upon the accuracy of this adjustment and must be considered in the selection of a micrometer. The transducer should be placed in a suitable temperature chamber and paragraphs 1 thru 3 of the INSTALLATION AND OPERATIONAL INSTRUCTIONS COMPLETED.

3.1.3 Perform paragraph 4 of the INSTALLATION AND OPERATION INSTRUCTIONS with the RANGE switch set to .03 IN.

3.1.4 With the controls set as in paragraph 3.1.3 above, displace the transducer core .03 inches and re-set the displacement potentiometer to 1000.

3.1.5 Calibration is achieved by adjusting for a zero or null indication as described in paragraph 5 of the INSTALLATION AND OPERATION INSTRUCTIONS excepting that the displacement potentiometer is left at 1000 and the appropriate calibration potentiometer numbers R230 thru R238 correspond to MT-1 thru MT-9.

3.1.6 Repeat paragraphs 3.1.3 thru 3.1.5 as required to eliminate interaction.

3.1.7 Repeat paragraphs 3.1.3 thru 3.1.6 but with the RANGE switch set to .003, displace the micrometer .003 inches, and adjust calibration potentiometer number R221 thru R229 (corresponding to MT-1 thru MT-9) as appropriate.

4. COMPONENT REPLACEMENT (Reference 4)

4.1 Replacement of CR1 thru CR69, R1 thru R18, and C1 thru C18 will not normally require re-calibration. If re-calibration is desired follow the steps in paragraph 3 for the transducer affected.

4.2 Replacement of R212 thru R220 and R230 thru R247 will require re-calibration as outlined in paragraph 3 for the transducers affected.

4.3 Replacement of R221 thru R229 will require re-calibration as outlined in paragraph 3 for the transducer affected but only on the .003 IN RANGE.

4.4 Replacement of R248 thru R337 and R201 thru R209 does affect calibration.

4.5 Replacement of R101, R107, R108, and C101, CR101 thru CR104, will not normally require re-calibration. See paragraph 4.6 below if desired.

4.6 Replacement of R102 thru R106, R109 thru R111, R210, and R211 may require re-calibration of R210 on the .03 IN RANGE and R211 on the .003 IN RANGE. These Potentiometers are normally set for average center range of the individual range calibration potentiometers. If a previously calibrated transducer is available follow the steps in paragraph 3 but use R210 to calibrate the .03 IN RANGE and R211 to calibrate the .003 IN RANGE.

APPENDIX C

INSTALLATION AND OPERATION INSTRUCTIONS
KAVLICO ELECTRONICS, INC.
GM-2105, SERIAL NO. 1002

1. SET-UP

   1.1 Connect the Transducers to Junction Blocks J1 thru J9 at the rear of the CONTROL PANEL chassis.

   1.2 Plug the AC POWER CORDS (Accessible from the back side of the console) into an 115 volt 60 cycle outlet.

2. POWER

   2.1 Turn the Power Supply LINE switch to ON position.

   2.2 Set the DC Null Meter RANGE switch to 10 (VOLTS).

   2.3 Turn the DC Null Voltmeter POWER switch to ON position.

   2.4 Set Power Supply OUTPUT meter to 22 volts. Turn the Power Supply OUTPUT switch to ON position.

3. TRANSDUCER MECHANICAL NULL

   3.1 Set CONTROL PANEL SWITCHES as follows:

      A. Set the CHANNEL SELECTOR switch to the transducer to be adjusted (MT-1 thru MT-9).

      B. Set the MECH NULL switch to MECH NULL.

      C. Set the POLARITY switch to direction of displacement to be measured (IN or OUT).

      D. Set the RANGE switch to desired full scale displacement (.03 IN or .003 IN).

      E. DISPLACEMENT potentiometer under the MT number under test to 000.

3.2 Reset the DC NULL VOLTMETER RANGE (VOLTS) switch as required to indicate the off null conditions.

3.3 Position the transducer core for minimum NULL METER deflection, while resetting the DC NULL VOLTMETER as in paragraph 3.2 above.

3.4 Report paragraph 3.1 thru 3.3 for each transducer (MT-1 thru MT-9) used.

4. ZERO SET

4.1 Set CONTROL PANEL SWITCHES as follows:

A. Set the CHANNEL SELECTOR switch to the transducer to be adjusted (MT-1 thru MT-9).

B. Set the MECH NULL switch to OPERATE.

C. Set the POLARITY switch to direction of displacement to be measured (IN or OUT).

D. Set the RANGE switch to desired full scale displacement (.03 IN or .003 IN).

E. Set the DISPLACEMENT potentiometer under the MT number under test to 000.

4.2 Reset the DC NULL VOLTMETER RANGE (VOLTS) switch as required to indicate the off null condition.

4.3 Set the COARSE ZERO adjustment switch (located under the MT number under test) for minimum NULL METER deflection, while resetting the DC NULL VOLTMETER as in paragraph 4.2 above.

4.4 Adjust the FINE ZERO adjustment potentiometer (located under the under the COARSE ZERO adjustment switch used in paragraph 4.3 above) for minimum NULL METER deflection, while resetting the DC NULL VOLTMETER as in paragraph 4.2 above. When the null adjustment is completed, lock the potentiometer to avoid accidental movement. If the potentiometer dial indication is recorded it can be reset if it should be accidentally moved.

4.5 Repeat paragraphs 4.1 thru 4.4 for each transducer (MT-1 thru MT-9) used.

5. DISPLACEMENT MEASUREMENT

5.1 Set CONTROL PANEL SWITCHES as follows:

A. Set the CHANNEL SELECTOR switch to the transducer to be measured (MT-1 thru MT-9).

B. Set the MECH NULL switch to OPERATE.

C. Set the POLARITY switch to direction of displacement to be measured (IN or OUT).

D. Set the RANGE switch to desired full scale displacement (.03 IN or .003 IN).

5.2 Reset the DC NULL VOLTMETER RANGE (VOLTS) switch as required to indicate the off null condition.

5.3 Adjust the DISPLACEMENT potentiometer, corresponding to the transducer selected in paragraph 5.1A above, for minimum NULL METER deflection, while resetting the DC NULL VOLTMETER as in paragraph 5.2 above. A lock is provided to avoid accidental movement after a null has been established and should be used if the DISPLACEMENT potentiometer indication is not recorded.

5.4 Repeat paragraphs 5.1 thru 5.3 for each transducer to be measured.

APPENDIX D

MAINTENANCE INSTRUCTIONS
KAVLICO ELECTRONICS, INC.
GM-2105, SERIAL NO. 1002

1. AC POWER SUPPLY

1.1 OUTPUT VOLTAGE ADJUSTMENT

Access to the power supply for voltage adjustment is by the knob on the oscillator unit marked "OUTPUT VOLTS ADJUST." It is de-desirable that this adjustment be made with full load, e.g., with the transducers connected. Output voltage should be monitored by a precision RMS Voltmeter (±0.2% Max.) while adjusting the FINE adjustment potentiometer, (inner knob), to give an output of 22 volts RMS.

1.2 REPAIR

Detailed prints, schematics, and instructions are contained in the Operational-Maintenance Manual for the power supply and the Instruction Manual for the oscillator. Re-set the output voltage as detailed in paragraph 1.1 after any repair. (References 1 and 2)

2. DC NULL VOLTMETER

2.1 RECORDER OPERATION

Before connecting a recorder to the output jacks note the limitations in paragraph 3-9, section 3 page 1 of the DC Null Voltmeter OPERATING AND SERVICE MANUAL. (Reference 3)

2.2 REPAIR

Detailed maintenance instructions are contained in the DC Null Voltmeter OPERATING AND SERVICE MANUAL. (Reference 3)

3. CONTROL PANEL

3.1 TRANSDUCER REPLACEMENT (Reference 4)

3.1.1 The transducers are serialized and as shipped are calibrated on both ranges (.03 IN and .003 IN) at a temperature of 550°F.

Serial Number 1001 is calibrated for MT-1 (Receptacle J1). Serial Numbers 1002 thru 1009 are similarly calibrated such that Serial Number 1009 is calibrated for MT-9 (Receptacle J9). In making a replacement the change in serial numbers must be noted to avoid errors in operational set-up.

3.1.2 Mount the transducer in a fixture such that the core can be displaced with a micrometer. Accuracy of measurements is dependent upon the accuracy of this adjustment and must be considered in the selection of a micrometer. The transducer should be placed in a suitable temperature chamber and paragraphs 1 thru 3 of the INSTALLATION AND OPERATIONAL INSTRUCTIONS COMPLETED.

3.1.3 Perform paragraph 4 of the INSTALLATION AND OPERATION INSTRUCTIONS with the RANGE switch set to .03 IN.

3.1.4 With the controls set as in paragraph 3.1.3 above, displace the transducer core .03 inches and re-set the displacement potentiometer to 1000.

3.1.5 Calibration is achieved by adjusting for a zero or null indication as described in paragraph 5 of the INSTALLATION AND OPERATION INSTRUCTIONS excepting that the displacement potentiometer numbers R230 thru R238 correspond to MT-1 thru MT-9.

3.1.6 Repeat paragraphs 3.1.3 thru 3.1.5 as required to eliminate interaction.

3.1.7 Repeat paragraphs 3.1.3 thru 3.1.6 but with the RANGE switch set to .003, displace the micrometer .003 inch, and adjust calibration potentiometer number R221 thru R229 (corresponding to MT-1 thru MT-9) as appropriate.

4. COMPONENT REPLACEMENT (Reference 4)

4.1 Replacement of CR1 thru CR69, R1 thru R18, and C1 thru C18 will not normally require re-calibration. If re-calibration is desired follow the steps in paragraph 3 for the transducer affected.

'.2 Replacement of R212 thru R220 and R230 thru R247 will require re-calibration as outlined in paragraph 3 for the transducers affected.

4.3 Replacement of R221 thru R229 will require re-calibration as outlined in paragraph 3 for the transducer affected but only on the .003 IN RANGE.

4.4 Replacement of R248 thru R337 and R201 thru R209 does affect calibration.

4.5 Replacement of R101, R107, R108, and C101, CR101 thru CR104, will not normally require re-calibration. See paragraph 4.6 below if desired.

4.6 Replacement of R102 thru R106, R109 thru R111, R210, and R211 may require re-calibration of R210 on the .03 IN RANGE and R211 on the .003 IN RANGE. These Potentiometers are normally set for average center range of the individual range calibration potentiometers. If a previously calibrated transducer is available follow the steps in paragraph 3 but use R210 to calibrate the .03 IN RANGE and R211 to calibrate the .003 IN RANGE.

N66-14251

6 April 1965

REPORT GD/C-64-213, REVISED MARCH 1965

ERRATA

Correct stress values are not entered in Tables 32 through 36, pages 82 to 91, of the published issue of the above report.

Sheets containing the correct stress values are attached.

Table 32 - Pages 82 and 83

Table 33 - Pages 84 and 85

Table 34 - Pages 86 and 87

Table 35 - Pages 88 and 89

Table 36 - Pages 90 and 91

Table 32. Onset of Creep Stress Measurement of Ti-8Al-1Mo-1V, Ti-6Al-4V and Ti-5Al-2 1/2 Sn Test Temperatures - 450°F Nominal (Sheet 1 of 2)

Elapsed Time Hrs	Front Test Channels								
	Ti-8-1-1 67.8 KSI	Ti-8-1-1 66.8 KSI	Ti-8-1-1 79.3 KSI	Ti-6-4 80.2 KSI	Ti-6-4 76.4 KSI	Ti-6-4 78.2 KSI	Ti-5-2 1/2 56.2 KSI	Ti-5-2 1/2 57.3 KSI	Ti-5-2 1/2 77.4 KSI
0	453.9	455.3	454.9	454.4	453.9	454.7	454.5	455.5	453.3
16	454.5	454.7	454.3	454.0	454.7	455.4	453.5	456.1	453.6
24	453.7	454.5	453.7	453.4	452.1	453.8	453.6	454.7	452.3
40	453.5	454.3	453.7	453.5	453.1	453.7	454.8	456.0	453.9
48	453.9	455.0	454.3	452.8	453.2	454.0	454.0	454.9	453.2
64	453.8	454.4	453.8	453.8	453.5	454.0	454.2	455.2	452.9
72	453.5	454.4	454.5	453.6	453.2	453.6	453.6	455.3	453.7
88	453.7	454.2	453.7	453.7	453.3	453.5	453.6	454.5	452.8
96	453.6	455.7	453.5	453.5	454.2	453.2	453.8	454.7	453.2
112	454.2	454.7	454.2	453.0	453.1	454.5	454.6	455.7	452.1
120	453.9	455.1	453.6	453.8	453.4	454.3	454.4	455.6	452.5
136	452.6	453.4	452.9	452.0	453.2	454.1	453.7	454.4	452.8
144	456.5	455.9	455.3	455.2	455.2	456.0	455.4	456.4	453.2
160	457.1	456.7	456.5	456.8	457.1	456.9	456.8	457.2	455.0

Table 32. Onset of Creep Stress Measurement of Ti-8Al-1Mo-1V, Ti-6Al-4V and Ti-5Al-2 1/2 Sn Test Temperature - 450° F Nominal (Sheet 2 of 2)

Elapsed Time Hrs	Rear Test Channels								
	Ti-8-1-1 66.7 KSI	Ti-8-1-1 65.2 KSI	Ti-8-1-1 78.8 KSI	Ti-6-4 82.0 KSI	Ti-6-4 77.3 KSI	Ti-6-4 79.2 KSI	Ti-5-2 1/2 56.4 KSI	Ti-5-2 1/2 59.5 KSI	Ti-5-2 1/2 76.8 KSI
0	453.5	455.1	453.9	455.6	453.9	453.9	455.3	455.7	455.5
16	451.1	454.2	453.2	456.1	452.9	453.3	454.4	455.0	454.6
24	450.4	453.0	451.9	454.4	451.6	452.0	453.9	453.9	453.6
40	450.6	453.9	454.6	455.3	450.4	450.5	452.7	454.7	453.1
48	452.6	454.3	452.3	454.2	452.4	451.9	454.0	454.9	454.2
64	451.6	453.6	451.7	454.0	452.1	451.7	453.7	455.4	454.3
72	453.6	455.5	453.2	455.7	453.1	453.1	456.4	455.7	453.6
88	452.2	453.6	451.5	453.8	452.5	452.0	453.7	454.4	453.8
96	452.4	454.1	451.6	452.8	452.3	453.3	451.7	454.7	454.2
112	454.0	454.9	452.8	455.4	454.1	452.7	453.7	456.2	455.3
120	453.6	454.3	452.2	455.1	453.7	452.5	453.5	456.2	454.5
136	453.0	455.0	453.4	456.1	452.8	452.5	453.2	456.5	454.7
144	455.4	455.0	456.8	458.9	455.5	456.3	455.4	457.6	456.8
160	456.8	456.9	457.7	459.8	456.7	457.5	456.3	457.9	458.1

Table 33. Onset of Creep Stress Measurement of Ti-8Al-1Mo-1V, Ti-6Al-4V and Ti-5Al-2 1/2 Sn Test Temperature - 500°F Nominal (Sheet 1 of 2)

Elapsed	Front Test Channels								
Time Hrs	Ti-8-1-1 63.2 KSI	Ti-8-1-1 63.2 KSI	Ti-8-1-1 72.3 KSI	Ti-6-4 81.6 KSI	Ti-6-4 76.3 KSI	Ti-6-4 82.2 KSI	Ti-5-2 1/2 57.8 KSI	Ti-5-2 1/2 73.8 KSI	Ti-5-2 1/2 82.5 KSI
0	502.95	504.00	503.30	503.90	503.15	503.20	503.30	504.95	501.50
20	503.95	504.30	504.00	503.75	503.80	504.25	504.25	505.10	501.35
28	502.60	502.80	502.50	502.55	502.60	502.80	502.65	503.35	501.95
44	502.90	503.65	503.10	503.25	503.10	503.45	503.10	505.00	501.55
52	499.45	499.70	499.65	500.05	499.30	499.15	500.05	500.90	499.88
68	500.45	501.05	500.83	500.25	500.40	500.70	500.75	501.90	499.95
76	500.45	500.80	499.30	500.20	500.25	500.80	500.62	502.10	499.65
92	512.00	512.70	511.98	512.95	511.90	511.85	513.00	513.45	513.90
100	500.65	501.90	501.15	501.15	500.90	501.30	502.10	502.63	501.90
116	500.95	501.60	501.25	502.95	501.40	501.45	501.80	502.13	499.60
124	499.60	500.05	500.50	500.50	500.75	500.80	501.25	501.50	501.25
141	500.25	500.85	500.13	500.80	500.30	500.50	501.35	500.50	499.80
169	499.30	500.70	500.85	503.75	505.50	500.70	501.50	501.83	504.45
188	499.30	501.35	502.35	502.55	501.90	502.00	502.05	502.15	502.90
196	495.70	497.40	497.60	497.20	498.25	498.00	497.50	498.60	495.50
212	498.75	500.30	500.55	501.75	500.60	500.65	501.65	501.08	502.25

Table 33. Onset of Creep Stress Measurement of Ti-8Al-1Mo-1V, Ti-6Al-4V and Ti-5Al-2 1/2 Sn Test Temperature - 500°F Nominal (Sheet 2 of 2)

Elapsed Time Hrs	Rear Test Channels								
	Ti-8-1-1 62.2 KSI	Ti-8-1-1 60.7 KSI	Ti-8-1-1 71.8 KSI	Ti-6-4 83.5 KSI	Ti-6-4 77.3 KSI	Ti-6-4 83.2 KSI	Ti-5-2 1/2 58.2 KSI	Ti-5-2 1/2 76.8 KSI	Ti-5-2 1/2 82.5 KSI
0	505.85	509.20	506.25	509.45	506.40	506.10	506.35	507.80	507.25
20	507.00	507.70	506.80	506.55	506.85	507.80	508.15	506.50	507.95
28	502.15	503.05	503.80	503.80	503.05	503.85	503.55	504.10	505.20
44	501.30	501.15	501.38	501.65	501.95	501.00	501.20	503.05	502.75
52	497.95	498.55	498.50	499.48	499.15	500.03	499.00	500.80	500.85
68	499.35	499.30	500.35	499.90	499.90	499.45	499.30	501.20	501.00
76	500.60	500.35	500.65	499.60	500.90	500.70	501.00	501.80	504.70
92	497.45	496.60	499.25	499.25	498.10	497.25	497.60	498.45	499.60
100	494.00	493.75	494.00	494.10	494.55	495.40	493.70	495.35	496.45
116	493.60	494.45	493.95	494.70	494.75	494.85	494.25	496.30	496.05
124	495.05	493.13	494.65	499.60	494.95	494.25	493.10	495.50	495.90
141	494.95	494.75	495.50	498.00	496.05	496.20	497.45	497.05	496.85
169	492.85	492.80	497.65	496.00	495.90	494.15	493.80	495.35	494.80
188	491.80	492.35	495.80	493.75	494.00	493.05	492.45	495.10	494.25
196	492.68	491.40	491.40	494.25	493.25	495.70	497.40	494.75	493.10
212	491.45	496.65	496.60	494.50	492.70	495.58	496.90	494.55	493.50

Table 34. Onset of Creep Stress Measurement of Ti-8Al-1Mo-1V, Ti-6Al-4V and Ti-5Al-2 1/2 Sn Test Temperature - 550°F Nominal (Sheet 1 of 2)

Elapsed Time Hrs	Front Test Channels Ti-8-1-1 70.4 KSI	Ti-8-1-1 60.5 KSI	Ti-8-1-1 68.7 KSI	Ti-6-4 68.2 KSI	Ti-6-4 63.5 KSI	Ti-6-4 71.3 KSI	Ti-5-2 1/2 60.2 KSI	Ti-5-2 1/2 60.8 KSI	Ti-5-2 1/2 80.8 KSI
0	543.70	545.95	546.50	545.95	546.45	546.50	545.90	545.80	546.05
20	543.10	545.45	547.00	547.30	546.55	546.15	546.70	544.40	546.20
40	543.40	545.35	547.10	547.20	546.40	546.70	546.65	546.00	546.20
48	542.95	544.60	545.35	546.15	544.70	545.30	546.45	544.00	545.80
64	544.60	546.00	545.95	546.60	545.75	546.75	546.65	546.50	545.95
72	543.85	545.05	545.50	546.45	545.80	545.10	546.15	546.20	544.80
88	546.15	546.80	548.55	545.90	548.55	548.75	547.93	547.00	547.75
96	544.55	546.15	547.15	546.85	547.40	548.70	548.23	546.70	548.70
112	547.95	548.80	548.83	548.60	549.23	548.50	548.20	548.95	550.05
120	544.05	546.85	548.53	546.80	549.05	548.10	548.40	548.00	550.65
136	544.20	546.35	547.00	548.50	548.25	549.10	548.20	546.85	551.45
144	543.55	545.90	543.38	547.88	547.10	547.75	546.95	546.40	548.45
160	546.85	546.95	548.85	550.50	549.35	547.50	547.30	546.43	550.75
184	547.25	550.00	550.50	551.70	550.60	550.65	550.05	550.40	552.30
208	547.30	549.65	550.00	551.40	550.05	550.50	551.15	550.10	548.80

Table 34. Onset of Creep Stress Measurement of Ti-8Al-1Mo-1V, Ti-6Al-4V and Ti-5Al-2 1/2 Sn Test Temperature - 550°F (Sheet 2 of 2)

Elapsed Time Hrs	Rear Test Channels								
	Ti-8-1-1 69.4 KSI	Ti-8-1-1 59.0 KSI	Ti-8-1-1 68.2 KSI	Ti-6-4 69.4 KSI	Ti-6-4 64.3 KSI	Ti-6-4 72.2 KSI	Ti-5-2 1/2 60.4 KSI	Ti-5-2 1/2 63.3 KSI	Ti-5-2 1/2 80.1 KSI
0	546.50	545.90	546.55	547.40	548.20	546.50	545.90	545.80	546.05
20	546.15	546.70	545.05	547.55	549.75	546.15	546.70	544.40	546.20
40	546.70	546.65	546.40	545.60	548.50	546.70	546.65	546.00	546.20
48	545.30	546.45	547.20	547.15	548.25	545.30	546.45	544.00	545.80
64	546.75	546.65	544.00	544.15	545.15	546.75	546.65	506.49	545.95
72	545.10	546.15	547.30	547.55	548.80	545.10	546.15	546.18	544.80
88	548.75	547.95	547.45	548.05	549.05	548.75	547.93	547.00	547.23
96	548.70	548.25	547.35	547.75	548.70	548.70	548.25	546.70	548.70
112	548.50	548.20	544.85	547.10	549.40	548.50	548.20	548.95	550.03
120	548.10	548.40	546.20	548.75	548.15	548.10	548.40	547.98	550.65
136	549.10	549.20	546.85	547.83	549.15	549.10	548.20	546.85	551.45
144	547.75	546.95	547.40	547.55	548.85	547.13	546.95	546.40	548.45
160	547.50	547.30	548.10	548.45	550.25	547.50	547.30	546.45	550.75
184	550.65	550.05	549.80	549.93	551.15	550.65	550.05	550.40	552.30
208	550.50	551.15	550.90	551.55	550.75	550.48	551.15	550.10	548.80

Table 35. Onset of Creep Stress Measurement of Ti-8Al-1Mo-1V, Ti-6Al-4V and Ti-5Al-2 1/2 Sn Test Temperature - 600°F Nominal (Sheet 1 of 2)

Elapsed Time Hrs	Front Test Channels								
	Ti-8-1-1 67.3 KSI	Ti-8-1-1 66.8 KSI	Ti-8-1-1 69.0 KSI	Ti-6-4 60.7 KSI	Ti-6-4 57.3 KSI	Ti-6-4 64.4 KSI	Ti-5-2 1/2 57.3 KSI	Ti-5-2 1/2 57.0 KSI	Ti-5-2 1/2 75.0 KSI
0	595.70	597.90	597.85	599.40	599.20	598.30	598.60	598.30	596.65
26	593.75	597.00	597.05	598.40	598.35	597.70	598.90	597.15	594.75
56	591.15	594.25	593.35	594.15	595.35	594.25	595.15	594.60	594.05
72	594.45	597.95	597.18	598.65	598.50	598.35	599.20	597.05	594.15
80	592.55	595.15	594.65	595.90	592.95	592.15	592.95	591.20	595.50
96	594.85	597.50	597.35	598.20	598.15	597.50	597.83	597.10	599.70
114	597.20	598.00	598.70	599.05	600.20	600.05	598.93	599.00	599.45
130	599.29	600.25	601.15	601.70	601.25	601.49	601.50	601.20	600.90
138	598.00	599.05	599.40	599.45	600.00	599.50	599.05	598.30	599.35
154	599.05	600.30	600.85	600.65	600.60	600.65	600.28	599.15	600.70
162	597.10	598.40	598.23	598.25	598.03	596.05	596.58	595.60	596.40

Table 35. Onset of Creep Stress Measurement of Ti-8Al-1Mo-1V, Ti-6Al-4V and Ti-5Al-2 1/2 Sn Test Temperature - 600°F Nominal (Sheet 2 of 2)

Elapsed Time Hrs	Rear Test Channels								
	Ti-8-1-1 66.7 KSI	Ti-8-1-1 65.0 KSI	Ti-8-1-1 68.8 KSI	Ti-6-4 62.0 KSI	Ti-6-4 58.2 KSI	Ti-6-4 63.8 KSI	Ti-5-2 1/2 58.7 KSI	Ti-5-2 1/2 59.3 KSI	Ti-5-2 1/2 74.3 KSI
0	593.65	592.35	593.50	595.85	595.10	591.40	593.40	591.75	591.45
26	593.50	592.55	592.85	594.40	595.20	592.45	593.80	592.30	591.20
56	592.20	590.90	591.55	593.95	594.80	591.15	592.30	591.10	589.80
72	593.65	592.50	593.65	594.10	594.60	591.45	593.15	592.35	591.50
80	587.60	587.90	587.33	588.50	589.00	585.70	587.60	585.45	585.80
96	592.80	592.40	593.15	593.05	594,65	591.80	592.85	592.05	591.50
114	598.65	597.70	598.95	599.43	600.30	599.60	599.20	597.90	597.93
130	601.45	601.45	601.35	601.30	601.10	599.85	600.60	598.35	596.80
138	601.40	601.50	601.90	599.80	600.95	600.60	600.30	598.70	598.45
154	601.95	601.73	602.03	599.85	601.10	599.95	599.50	598.90	597.85
162	600.20	600.70	597.35	599.10	600.35	598.90	601.05	601.65	601.89

Table 36. Onset of Creep Stress Measurement of Ti-8Al-1Mo-1V, Ti-6Al-4V and Ti-5Al-2 1/2 Sn Test Temperature - 650°F Nominal (Sheet 1 of 2)

Elapsed Time Hrs	Front Test Channels								
	Ti-8-1-1 52.6 KSI	Ti-8-1-1 49.3 KSI	Ti-8-1-1 55.6 KSI	Ti-6-4 48.2 KSI	Ti-6-4 46.5 KSI	Ti-6-4 55.3 KSI	Ti-5-2 1/2 51.2 KSI	Ti-5-2 1/2 53.3 KSI	Ti-5-2 1/2 68.9 KSI
0	658.75	658.85	657.90	658.55	655.80	654.75	653.78	654.40	656.00
24	652.70	653.75	653.70	655.53	654.70	654.50	654.40	653.60	655.85
32	650.10	652.20	651.35	653.35	652.53	651.90	651.70	650.70	652.45
48	649.00	648.50	651.45	652.90	651.75	651.18	651.33	651.10	651.10
56	648.50	647.45	648.15	649.10	648.60	648.65	648.25	647.70	648.75
72	649.20	650.95	649.85	652.05	652.07	652.00	651.80	650.90	652.45
96			Recorder Non-Operative						
114			Recorder Non-Operative						
133			Recorder Non-Operative						
156			Recorder Non-Operative						
178	647.40	649.00	649.33	650.95	650.30	650.25	650.55	649.65	649.95
186	647.60	649.80	649.43	651.90	651.70	650.80	649.85	651.20	652.25
194	647.33	649.58	650.05	650.75	650.80	650.90	659.55	651.08	650.15
210	646.88	646.93	650.15	650.78	649.75	650.58	649.75	650.65	650.10
236	646.65	648.50	648.45	649.90	649.60	649.15	647.70	648.10	648.75

Table 36. Onset of Creep Stress Measurement of Ti-8Al-1Mo-1V, Ti-6Al-4V and Ti-5Al-2 1/2 Sn Test Temperature -650°F Nominal (Sheet 2 of 2)

Elapsed Time Hrs	Rear Test Channels								
	Ti-8-1-1 57.1 KSI	Ti-8-1-1 58.5 KSI	Ti-8-1-1 64.6 KSI	Ti-6-4 51.2 KSI	Ti-6-4 55.8 KSI	Ti-6-4 60.7 KSI	Ti-5-2 1/2 57.7 KSI	Ti-5-2 1/2 62.1 KSI	Ti-5-2 1/2 61.0 KSI
0	647.15	646.70	647.40	648.45	646.70	645.95	646.15	645.65	646.65
24	649.50	650.95	649.95	650.15	649.65	649.15	649.00	648.70	648.93
32	644.30	644.05	644.60	645.30	646.50	643.70	644.50	644.13	642.10
48	646.90	645.95	645.50	643.90	644.30	642.55	643.95	643.35	642.78
56	646.00	646.05	645.90	645.65	646.65	644.10	644.00	644.50	643.45
72	651.60	651.45	650.20	653.55	653.65	651.55	651.80	650.75	650.25
96				Recorder Non-Operative					
114				Recorder Non-Operative					
133				Recorder Non-Operative					
156				Recorder Non-Operative					
178	648.20	648.60	649.95	650.15	650.20	646.35	647.65	647.25	645.50
186	648.35	649.10	649.30	650.10	650.55	647.40	649.00	648.00	646.35
194	647.60	648.35	649.05	649.40	650.20	648.65	646.20	646.90	646.15
210	647.75	647.80	648.60	648.60	650.65	646.90	647.40	646.95	645.45
236	646.60	647.30	648.05	648.80	649.85	646.60	647.30	646.85	644.60